BIOLOGY OF AGE O+ SAND FLOUNDER *RHOMBOSOLEA PLEBEIA* IN THE AVON-HEATHCOTE ESTUARY

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by

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1. INTRODUCTION

1.1 Introduction and Previous Work

The sand flounder Rhombosolea plebeia (Richardson) (Pleuronectidae) inhabits shallow coastal marine and brackish water regions throughout New Zealand, Auckland Islands and possibly Australia.

Relatively little research has been carried out on this important commercial species. The principal investigation up to the present time is an unpublished Ph.D. thesis by Mundy (1968), who carried out a population study involving tagging of adult fish off the Canterbury coast. Some data were provided as part of a study on the fish population of the Avon-Heathcote Estuary by Webb (1966, 1972, 1973a, 1973b). A Ph.D. study on osmoregulation of sand flounder from Otago Harbour has been completed by Raj (1973), and a study of flounder spawning in the Hauraki Gulf has also been recently published by Colman (1973).

The shallow water inlets and estuaries around the Canterbury coast act as a nursery for young stages of sand flounder. While some population and feeding studies have been carried out on the older age classes, little is known of its early development, natural history and physiology. The Avon-Heathcote Estuary (latitude $43^{o}32'$S., longitude $172^{o}43'$E.), the study area in the present investigation (Fig. 1), is one of these nursery areas for the young stages. It is probably the principal area for producing fish to restock the offshore grounds which provide the commercial catches on the east coast of the South Island (Mundy, 1968).

Sand flounder is an important commercial species, both in terms of public demand and in the volume of landings. The annual landings of flounder of all species in New Zealand from 1944-1970 was about 907,730 kg, and of this total sand flounder formed about 50 percent (New Zealand Marine Department, Reports on Fisheries, 1944-1970). Hence the study of its biology in a major nursery area and of the effects of man-made environmental changes and pollution is important.

The Christchurch Drainage Board proposes to control flooding in the City of Christchurch and have had several flood control schemes tested by the Hydraulics Research Station, Wallingford, England. They have also commissioned an intensive biological research programme on the Avon-Heathcote Estuary headed by Professor G.A. Knox, Department of Zoology, University of Canterbury to assess the effects of these flood control schemes. The present study forms part of this biological research programme.

The flood control schemes include proposals to erect a barrier near the Estuary mouth. If spring tides coincide with heavy rainfall, surface flooding in parts of Christchurch becomes a problem. When flooding is imminent it is proposed that the barrier gates will be closed at low water to prevent tidal penetration so that flood water can drain into the Estuary without being retarded by the incoming tide. Any such scheme affecting the biology of the Estuary must be carefully considered as undesirable effects may result.

The first general study of the biology of the Estuary was made by Thompson (1930), whose work forms a useful basis with which to compare changes that have occurred since then. More specific studies have been made on polychaetes (Estcourt, 1962), fish populations (Webb, 1966), sand flounder (Mundy, 1968) and benthic macrofauna (Voller, 1973), and a number of surveys directed at the effect of pollution in the Estuary have been carried out by Bruce (1953), Williams (1959), Rosenburg (1963), Webb (1965) and Cameron (1969). Pollution studies of the Avon and Heathcote Rivers have been published by Hogan and Wilkinson (1959) and Cameron (1970). Other studies including Estuary populations as part of more extensive research have also been carried out (for a complete bibliography see Knox and Kilner, 1973).

Research currently in progress, in addition to the 0+ sand flounder study, include studies on the algal communities, a water chemical analysis programme and a investigation of the biology of the Christchurch Drainage Board's Sewage Oxidation Ponds.

A report on the general ecology of the Estuary has been prepared recently (Knox and Kilner, 1973), and this summarizes much of the above material and includes other relevant information.

1.2 Aims of the Present Study

The aim of the present study was to contribute to an understanding of the biology of age 0+ sand flounder in the Avon-Heathcote Estuary, and in particular:

a) To investigate the timing and method of entry of the larvae to the estuarine population;

b) To provide an account of growth by monthly length frequency analyses, and length : weight relationships;

c) To investigate the food and feeding habits;

d) To investigate the distribution of the fish, with emphasis on the effect of salinity; and

e) To assess the effect of the proposed barrier.

The study was largely confined to age 0+ sand flounder, since this age class predominates numerically in the Estuary and as the role of the Estuary as a nursery was being investigated. Tesch's (1968) terminology has been followed where 0+ fish are those in their first growing season.

2. DESCRIPTION OF STUDY AREA AND SAMPLING METHODS

2.1 Physical Description of the Study Area

The Avon-Heathcote Estuary is a bar-built estuary lying immediately north of Banks Peninsula (Fig. 1). The Estuary has an area of about 8 km^2 and is roughly the shape of an equilateral triangle (Plate 1).

The Avon and Heathcote Rivers are springfed and slow-flowing and enter the Estuary at the north and southwest corners respectively. Their sources and upper reaches are described by Hogan and Wilkinson (1959). Together they drain about 390 km^2 of catchment area most of which is in the City of Christchurch.

Effluent from the Christchurch Drainage Board's Sewage Works is discharged into the western side of the Estuary near the mouth of the Avon River.

The Estuary is a 'normal' estuary, that is, inflow of river water is greater than losses by evaporation. There is net outflow of water to the sea, and salinities are reduced up-stream by mixing with river water. At low tide the greater part of the Estuary is exposed as mudflats, and water is confined to a series of low-tidal channels (shown by the broken lines in Fig. 1).

The following parameters were investigated because it was considered that they were relevant to the biology of 0+ sand flounder.

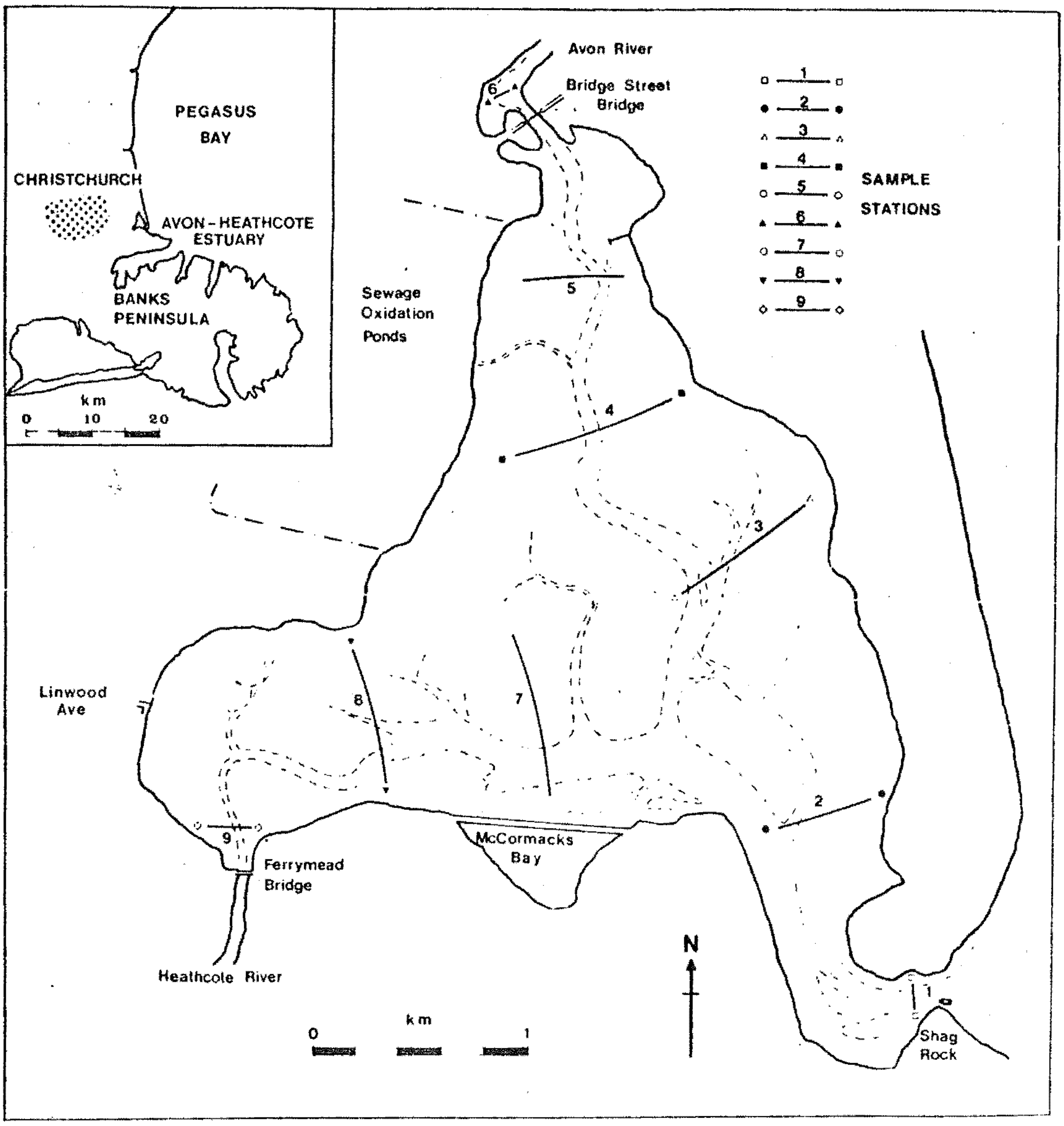


Fig. 1: Avon-Heathcote Estuary showing the major sample stations used during the study.

Plate 1: Aerial photograph of Avon-Heathcote Estuary, viewed from mouth.

Photo: F. McGregor.

Temperature

Air temperature, rainfall and evaporation were recorded at Bromley Sewage Works.

Water temperatures were recorded as frequently as possible, at least one set of spot recordings usually being obtained each week. Minimum temperatures occurred in July and maxima in December-February (Fig. 2A). Water temperatures generally fluctuated within the mean maximum and mean minimum air temperatures, and mean water temperatures closely paralleled those recorded by Escourt (1962) and Webb (1966). The mean water temperature was also higher than sea surface temperatures recorded off the Canterbury coast in 1966-1968 by Coakley (1970). Estcourt (1962) noted a similar phenomenon.

Estcourt found that generally water temperatures within the Estuary have greater ranges and fluctuate more than sea temperatures, while air temperatures have smaller ranges and less fluctuation than those recorded on the land at Christchurch Botanic Gardens.

Rainfall

Bromley had a mean annual rainfall of 553 mm over the period 1962-1972 (New Zealand Meteorological Records, 1962-1972). The monthly rainfall and evaporation figures obtained during the period of the study are shown in Fig. 2B. High rainfall and low air temperatures occurred during the winter (May to August) and during this period evaporation was low. As temperatures rose towards summer evaporation increased. In hot summer periods high temperatures may lead to depletion of dissolved oxygen in the water of some pools and streams on the mudflats and could effect the fish.

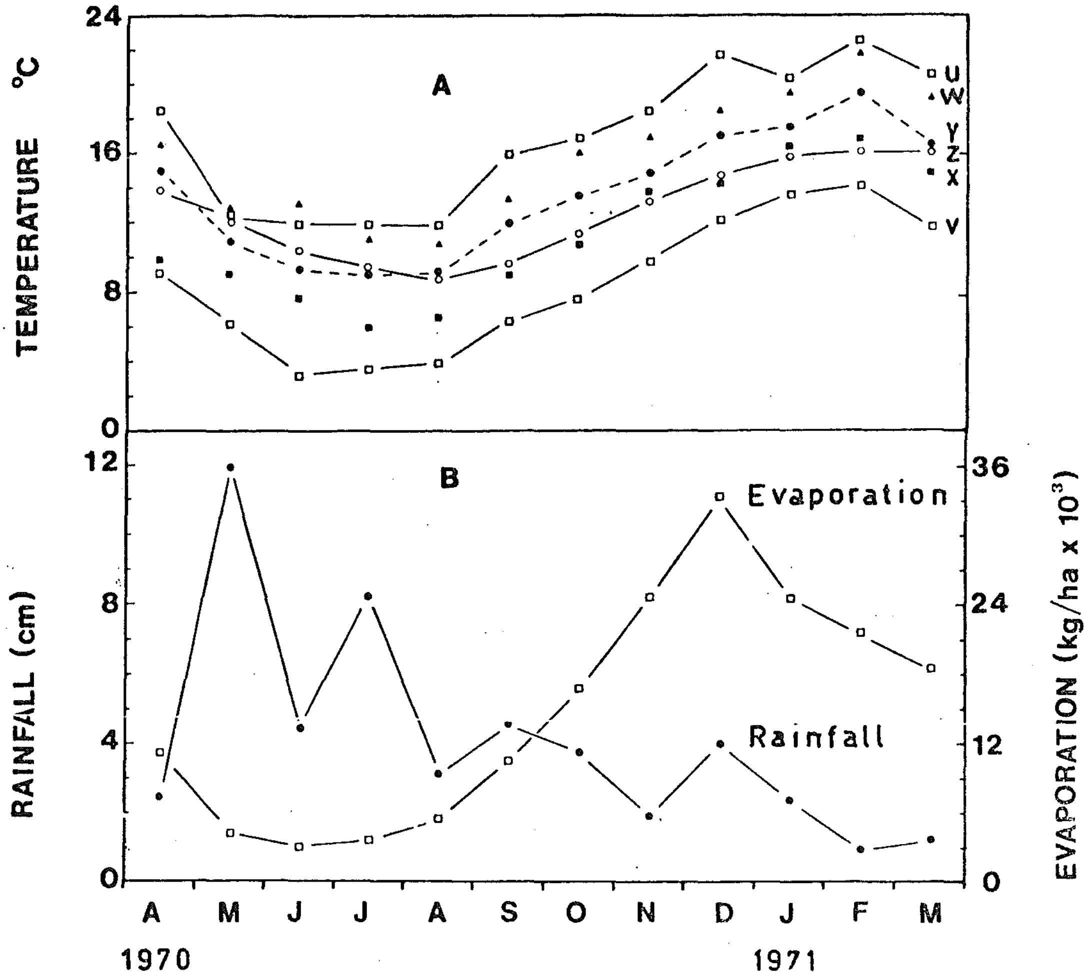


Fig. 2A: Temperatures recorded at the Avon-Heathcote Estuary

U Mean maximum air temperature*
V Mean minimum air temperature*
W Maximum Estuary water temperature
X Minimum Estuary water temperature
Y Mean Estuary water temperature
Z Mean sea temperature (Coakley, 1970)

Fig. 2B: Rainfall and evaporation at the Avon-Heathcote Estuary*

*Recordings taken at Bromley Sewage Works.

Tidal Flow and Currents

The tide is semi-diurnal with a range of 2.13 metres for spring tides and 1.06 metres for neap tides.

The general pattern of water movement within the Estuary has been described by Linzey (1944) and Webb (1972). With the onset of the flood tide, water penetrates into the Estuary and overcomes the ebb tide momentum so that tidal flow is reversed. The change in direction occurs later and later upstream. Following this direction change water starts to flow out over the mudflats. As the two rivers are constantly flowing there is a relative shortening of the length of the flood tide by the downstream pressure of the river water. Thus the ebb tide is longer than the flood tide. The majority of the mudflats are uncovered for 4-8 hours and parts for greater than 8 hours of each tidal cycle.

Current velocities were determined under conditions of normal river flow at Stations 1, 3 and 6 (Fig. 1) and are shown in Fig. 3. The stations were located in mid-channel and measurements were made 15 cm above the bottom and below the surface using a Gurley No. 622 Current Meter. Maximum bottom current velocities were recorded at the mouth (Station 1) and decreased further up the Estuary. The Hydraulics Station, Wallingford, England (Report No. EX509, 1970) found similar current patterns at Stations 1 and 6, but Linzey (1944) recorded much lower velocities. River discharge rates at the times of his measurements are not known.

In addition to data recorded in mid-channel, measurements were made above the mudflats at Station 3 at mid-tidal levels. This station was chosen for making these additional measurements

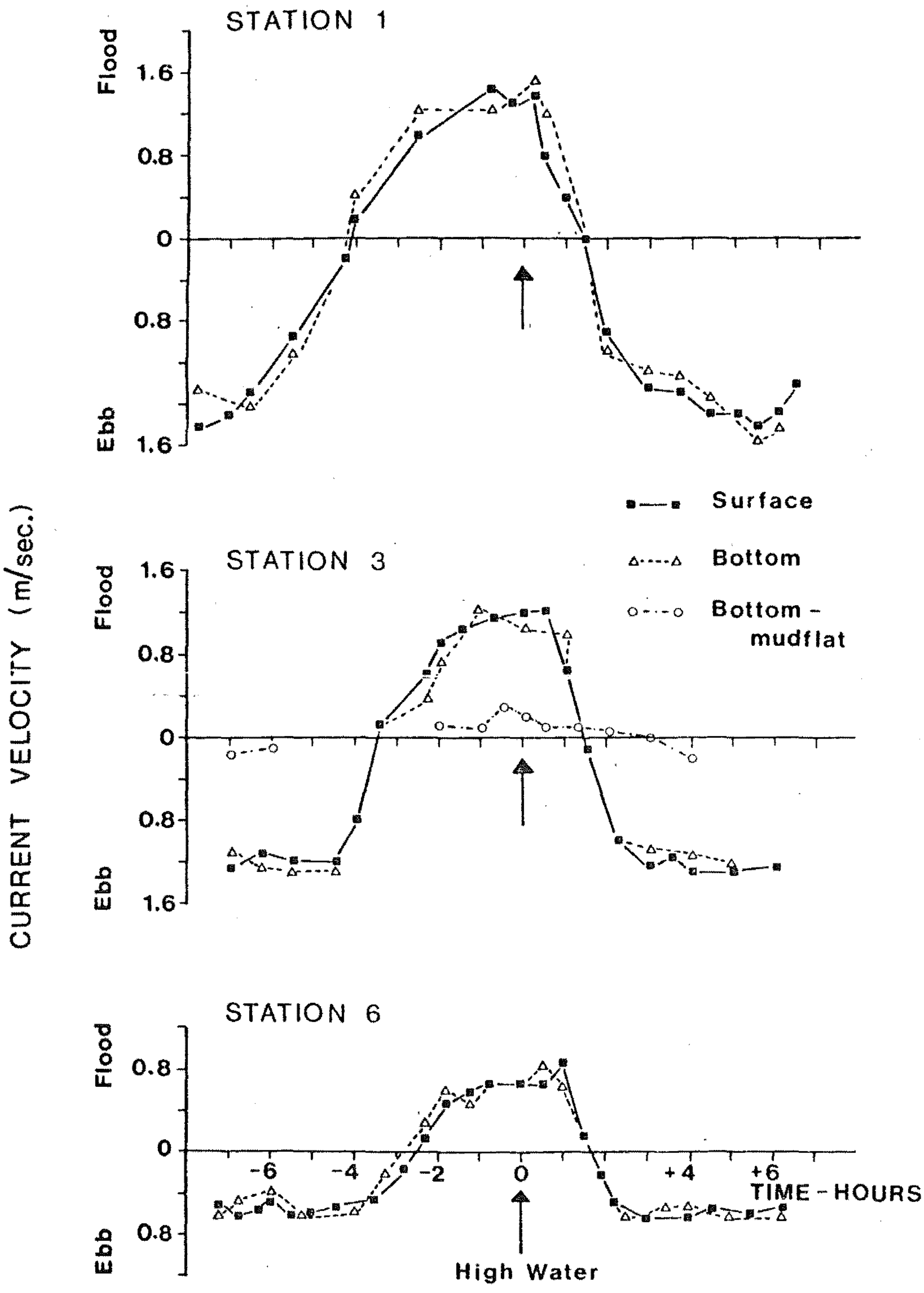


Fig. 3: Current velocities measured at Stations 1, 3 and 6 in May 1970.

because flounder were most abundant there. Velocities were much lower than those in mid-channel, the maximum velocity being 0.3 m/sec compared with 1.2 m/sec in mid-channel.

Salinity

Information on salinity changes in the Estuary over complete tidal cycles was required for the present study as salinity probably has a strong influence on the distribution of a estuarine-dependent fish. As no general account of salinity changes in the Estuary was available, six stations (Stations 1-6) were established in mid-channel at regular intervals up the Estuary (Fig. 1) so as to provide a salinity gradient. Samples were taken from a boat and at each station bottom-, mid- and surface-water samples were collected using a horizontal water sampler (Plate 2) modified from the design of Howmiller and Sloey (1969). Each time the sampler was lowered to the required depth care was taken that all water inside it was replaced by water from the required depth before the messenger was released.

All stations were sampled in May and November, 1970 during periods of neap tides. Two or three stations were sampled each sampling day at $\frac{1}{4}$ - $\frac{1}{2}$ hour intervals over complete tidal cycles. As a complete series of samples took several days to collect, care had to be taken to select periods when climatic and tidal conditions were similar, so as to minimize sampling variation.

Samples were brought back to the laboratory in sealed jars and salinities were measured using an Inductive Salinometer Model 601 Mark 3 (Autolab. Industries Pty. Ltd.) standardized against Copenhagen Standard Sea Water.

Salinities obtained in May 1970 are shown in Fig. 4. A distinct salinity gradient was found in the Estuary, salinities

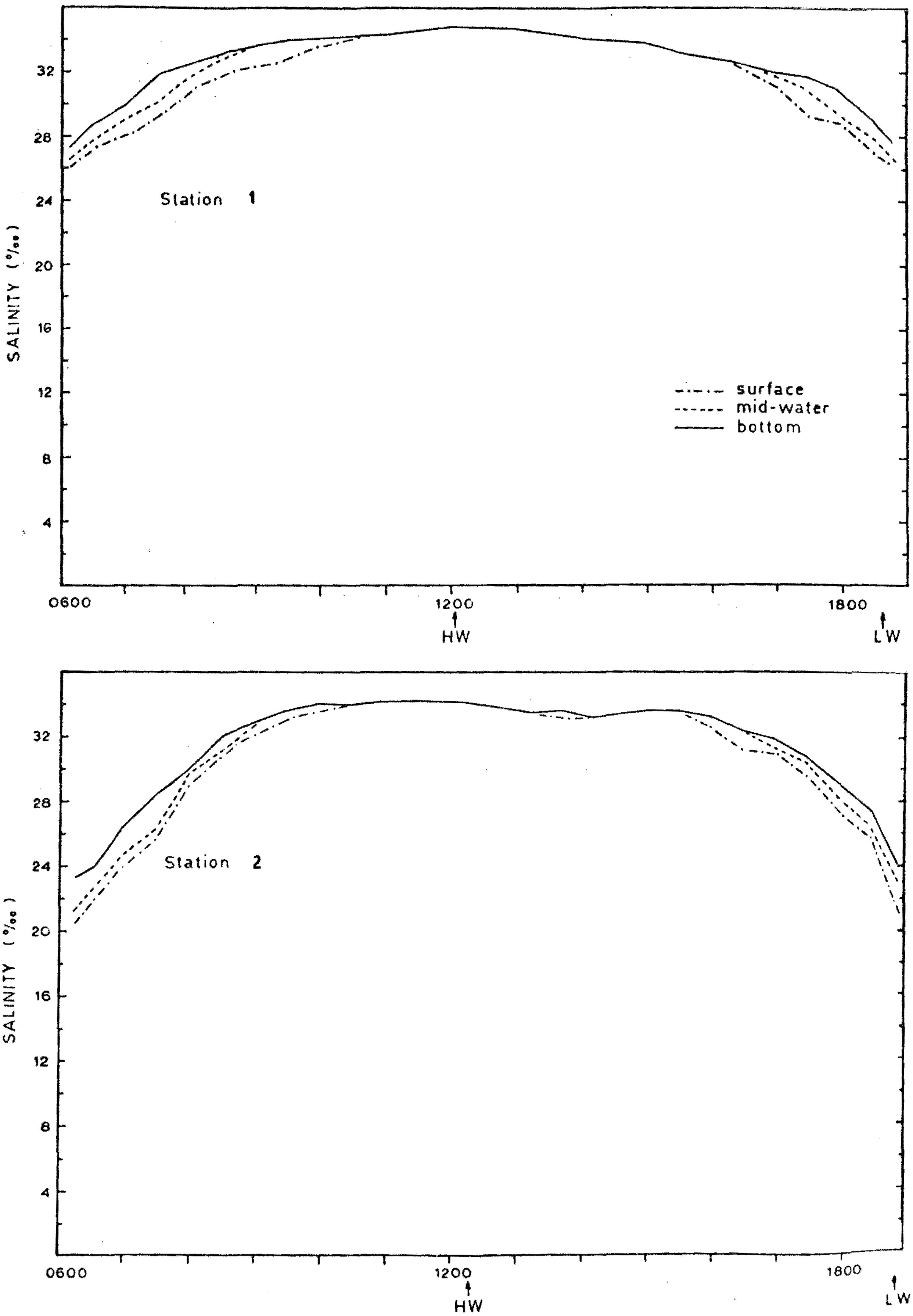
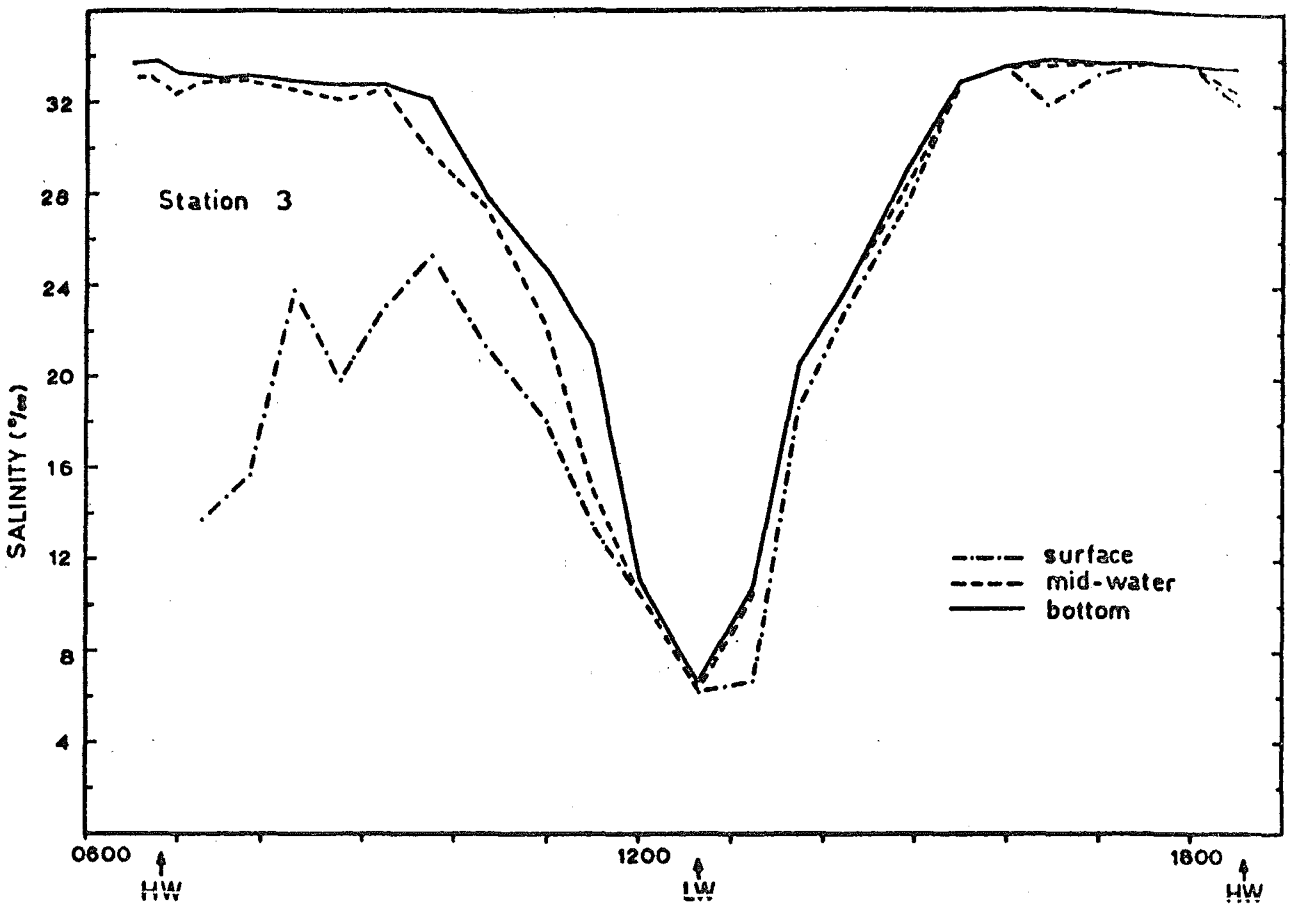


Fig. 4: A series of salinity measurements taken over full tidal cycles at Stations 1-6 in May 1970.



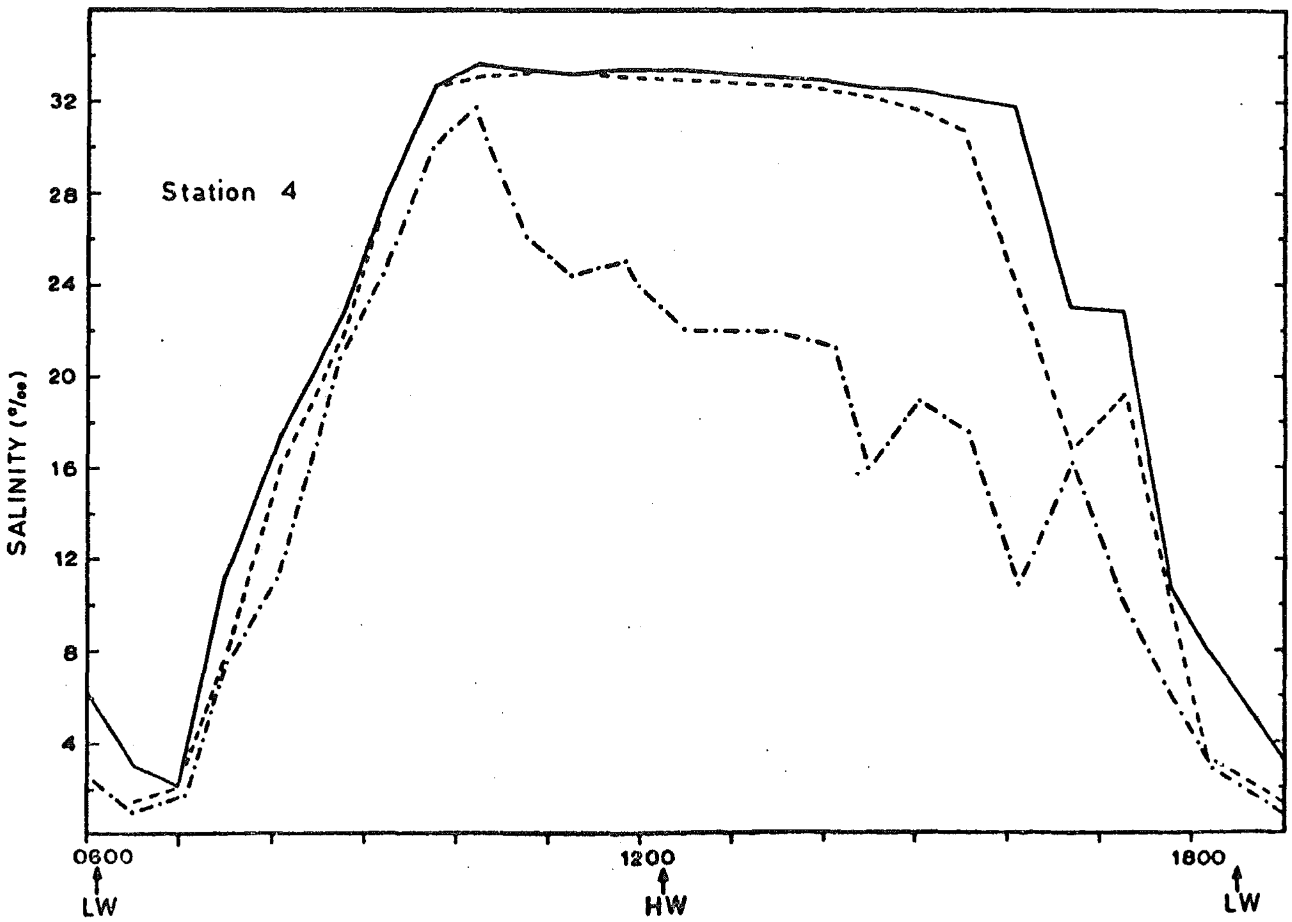


Fig. 4: (continued).

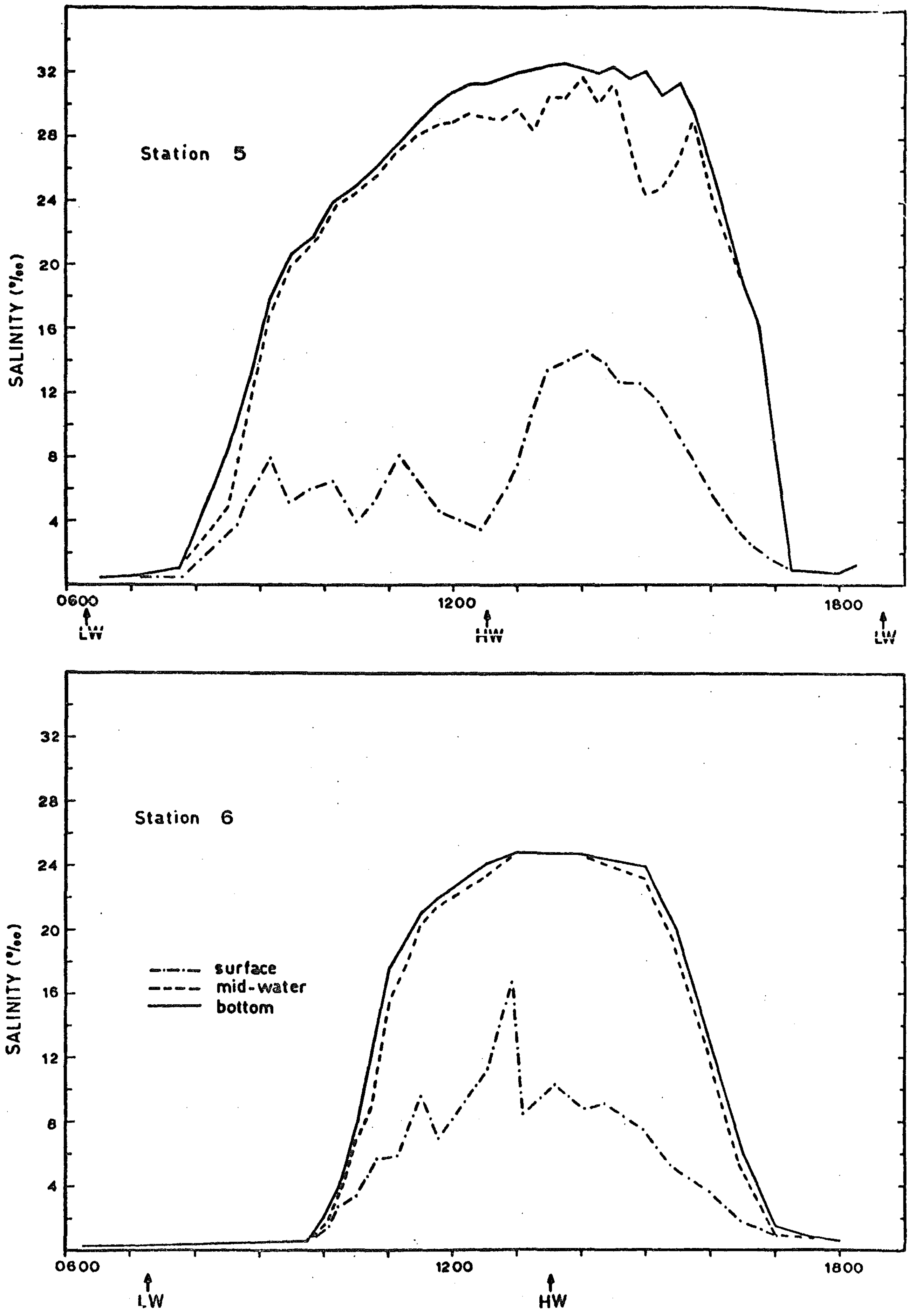


Fig. 4: (continued).

at the mouth being essentially those of the open sea, except for a very short period at low water when a minimum salinity of 23^{o}/oo was recorded. Further up the Estuary salinities at low water became progressively lower (from Station 4 onwards they became < 1^{o}/oo) and this low salinity phase took up an increasingly longer period of the tidal cycle. At Station 6 the situation was the reverse of that at the mouth, the high salinity phase at high water now being of very short duration. Linzey (1944) and Bruce (1953) obtained similar results for Station 6 as did Hydraulics Research Station (1970) for Stations 1 and 6. The November salinities followed a similar pattern to those taken in May. By contrast, Hogan and Wilkinson (1959) found distinctly lower salinities in winter than summer resulting from increased runoff. Nevertheless, seasonal salinity changes in the Estuary are unlikely to be extremely marked owing to the temperate climate and relatively low rainfall of the region.

On spring tides when more salt water enters the Estuary than on other tides, the salinity at Station 3 was not observed to drop below 11^{o}/oo whereas on neap tides it dropped to 5-7^{o}/oo.

The Estuary showed a 'salt wedge' effect at the upper stations on calm days, and this was particularly clear at Stations 5 and 6. The curves for bottom- and mid-water salinities closely approximated each other with the highest salinities occurring at or after high water. There were considerable differences between the mid- and surface-water salinities about the time of high water, however. At Station 5 mid-water salinity was 29.2^{o}/oo and surface salinity 4.3^{o}/oo at high water, while at Station 6 mid-water salinity was 24.8^{o}/oo and surface salinity 8.6^{o}/oo.

Station 4 showed a similar pattern although the difference between mid- and surface-water salinities was less marked. Station 3 was of particular interest, as when sampling started at high water there was a 15^{o}/oo difference between mid- and surface-water salinity, but on the succeeding flood tide no marked stratification was observed, and salinities were similar at all depths. On a separate occasion while sampling at Station 3 a strong northwest wind arose and within 30 minutes the vertical salinity gradient in a depth of 3.5 metres was disrupted and complete mixing occurred through turbulence.

These data indicate that under certain conditions a modified salt wedge which could be described as a two layered flow with partial mixing can develop. It appears that calm conditions are required for development of vertical stratification and with strong winds a more homogeneous layer of water occurs. On the shallower mud-banks turbulent mixing prevents development of marked vertical stratification patterns. It has also been shown that the water that flows out over the mudflats is predominantly sea water and little freshwater is present (Voller, 1973).

The magnitude and rates of salinity change were calculated from the data presented in Fig. 4 and are shown in Table 1. Both magnitude and rate of salinity change are large in the upper parts of the Estuary (Stations 3-6) especially in the bottom water. However, the rate of salinity change is not significantly different between these stations.

Table 1: Magnitude and rates of salinity change during complete tidal cycles at Stations 1-6.

Station	Magnitude of salinity change (°/oo)		Maximum rate of salinity change/hour (°/oo)	
	Surface	Bottom	Surface	Bottom
1	6	9	2.5	3.5
2	11	13	5	6.5
3	24	29	7	15
4	29	33	12	17
5	14.5	33	8	19
6	12	24	5	16

2.2 Sampling Methods

Sampling Equipment

A preliminary investigation using several types of sampling gear was undertaken to determine the best method for capturing 0+ sand flounder. The results are briefly summarized below.

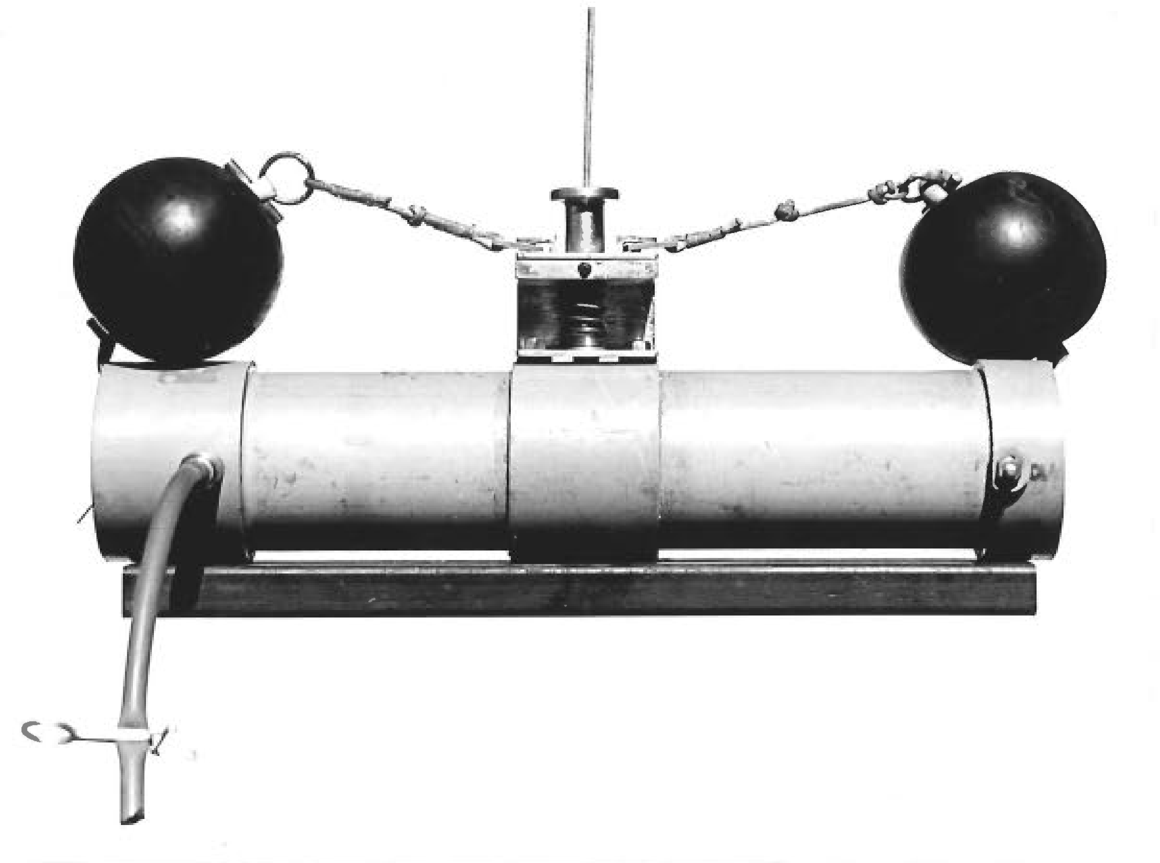
1. Hand nets did not provide quantitative samples.
2. A push net (Muus, 1967) could be used in shallow water where the substrate was firm underfoot but this net excluded sampling most channels.
3. Trap nets, modified from a design by Crowe (1950), collected floating algae causing the nets to collapse, and the current dug out sediment from under the nets allowing fish to escape.
4. Beach seines could be used during the relatively short periods of slack water in the channels, however they could not be used over the mudflats at high water to investigate the movements of fish.
5. Otter trawls were too cumbersome to use in narrow channels.
6. A beam trawl (Plate 3) proved to be the most satisfactory equipment.

Plate 2: Horizontal water sampling bottle (volume 2.5 l).

Photo: H. Best.

Plate 3: Beam Trawl.

Photo: H. Best.



The beam trawl had the following dimensions: width 1.5 m, height 0.4 m and length 4.5 m. Two tickler chains were used as Riley and Corlett (1965) found that they gave a marked increase in the catch; this was borne out in the present study. The trawl was towed by a 3 metre boat propelled by an 8 horse power outboard motor. A field experiment showed that 1.27 cm ($\frac{1}{2}$ in) stretch mesh obtained a more representative sample of juveniles than 3.18 cm ($1\frac{1}{4}$ in) stretch mesh (see Chapter 4). Two and four metre width beam trawls have been used extensively in recent years in studies of young flatfish (Riley and Corlett, 1965; Macer, 1967; and Edwards and Steele, 1968). In the present study a smaller trawl was constructed for more convenient use with the small boat and in the shallow water.

Two methods were used for operating the beam trawl. In water over 0.75 m depth the trawl was towed by boat, care being taken to avoid hauling the trawl over the same path as the boat where fish may have been disturbed. In shallower water the trawl was hauled by hand. On some occasions a hand net was employed to sample very small fish in mudflat pools; these catches were not compared with the beam trawl catches however, because of statistical differences in size and numbers of fish captured.

The problems encountered in studying fish populations in the Estuary have been fully outlined by Webb (1966, pp. 7-9). The problems he met; currents, wind, algae, underwater obstacles, shifting channels, ineffective sampling gear and human interference were all encountered in my study. Such difficulties are inherent in fisheries biology in this type of estuary and the planning of the study has to be adapted to minimize their effects as much as possible.

Estimates of efficiency of the beam trawl in capturing fish were unsuccessful. The marked seasonal change in size and abundance of young fish, the seasonal change in algal density, and the difference in the softness of the sediments between stations all precluded escapement calculation except by a major study beyond the scope of the present work. With young flatfish Riley and Corlett (1965) estimated 43% escapement with a 4 m beam trawl. Whereas Edwards and Steele (1968) estimated 63-77% escapement with a 2 m beam trawl. Considering the difficulties encountered in sampling the Estuary a high order of escapement probably occurred.

Sampling Programme

The sampling programme was directed at capturing fish from six sample stations (Stations 1-6 in Fig. 1) for a year to obtain samples for gut analysis, length frequency, condition and distribution. On one day each month all six stations were sampled, and on other days further sampling was undertaken to elucidate particular features of the fishes biology. For the latter the methods used have been included in the text of the relevant Chapter.

Sample Stations

The positions of the six sample stations are shown in Fig. 1. These stations were selected to provide a range of salinities, current velocities, sediment types and levels of pollution so as to assess the effect of these parameters on the biology of the sand flounder.

Sediments are relatively coarse and sandy at the mouth of the Estuary (Station 1 sediments have < 20% silt-clay) and show a gradual transition to more silty conditions at the head

(40-90% silt-clay at Stations 5 and 6). There is a intertidal transition from finer sediments at lower intertidal levels to coarser sediments at higher intertidal levels (Voller, 1973).

High levels of organic matter and nutrients in the sediments are associated with sediments high in silt-clay content. The levels of organic matter and nutrients therefore parallel the change in sediment structure in the Estuary. Full accounts of the sediments and the manner of their formation may be found in Knox and Kilner (1973) and Voller (1973).

Chemical analyses of the water showed a similar transition of high concentrations of phosphorus and nitrogen at the head of the Estuary near the nutrient sources, the Sewage Oxidation Pond Outfalls and the rivers, and lower values near the mouth where the greatest dilution by sea water occurs (Knox and Kilner, 1973).

Identification of 0+ Sand Flounder

The identification of 0+ sand flounder has proved to be a problem as there are three species of flatfish which are common in the Estuary: sand flounder *Rhombosolea plebeia* (Richardson), yellow-bellied flounder *Rhombosolea leporina* Gunther and English Sole *Peltorhamphus novaezeelandiae* Gunther. Identification of adult stages of these species is not difficult, but separation of juvenile sand flounder and yellow-bellied flounder is difficult.

Manikiam (1969) separates the two species on three characters:

1. Sand flounder have larger eyes than yellow-bellied flounder, the eye diameter being 1/4-1/6 the length of the head, whereas in yellow-bellied flounder they are 1/6-1/8.
2. Sand flounder possess fewer gill rakers in the lower half of the first arch, their numbers ranging from 12-18, with a mean of 16. Yellow-bellied flounder have a range of

12-23 with a mean of 19.

3. Dorsal rays are said to be more numerous in sand flounder, ranging from 53-63 with a mean of 59. Yellow-bellied flounder have 54-63 with a mean of 59. The values given by Manikiam, especially for dorsal rays, are inadequate to clearly separate the two species.

None of these characters is entirely suitable for use in the field where rapid identification of live juveniles was necessary. However preliminary investigations suggested that a difference in body proportions might occur between the species, the sand flounder appearing to have a greater width to length ratio. A sample of juvenile fish of both species having a wide range of total lengths was selected for analysis. For each fish both the total length from the tip of the closed mouth to the end of the longest caudal fin ray stretched out posteriorly, and the widest part of the body just posterior to the pectoral fin on the non-pigmented surface were measured to the nearest millimetre. Each fish was then identified to species using Manikiam's characters. Regression lines were calculated from these data using Bartlett's (1949) three-group method since both the independent and dependent variables are subject to error (Fig. 5).

The variances complied with the conditions of homogeneity of variances (Bartletts test for homogeneity of variances) as a chi-square value of 3.0 was obtained compared with the critical $\chi^2_{0.01}$ value of 6.63 for one degree of freedom. As the variances were homogeneous the two regressions could be compared for differences in slope and intercept by analysis of covariance. Analysis of covariance revealed significant differences between the slopes (F value = 296.43 for 1,81 degrees of freedom) and between the points of intercept on the axis (F value = 103.72

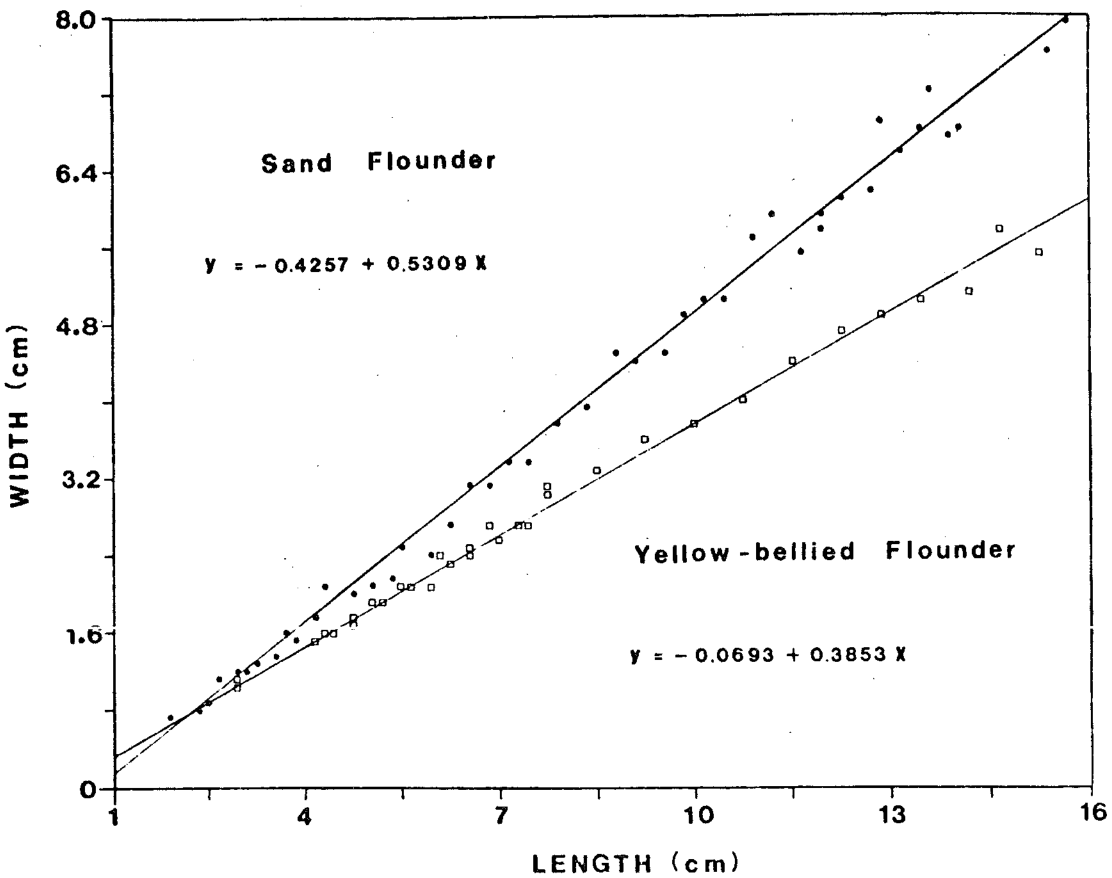


Fig. 5: Length:width relationships for 0+ sand flounder and 0+ yellow-bellied flounder.

Sand flounder	N = 45
	Y = -0.4257 + 0.5308X
	r = 0.997*
Yellow-bellied flounder	N = 40
	Y = -0.0693 + 0.3853X
	r = 0.996*

*Correlation coefficients (r) were significant at the 1% level.

for 1,82 degrees of freedom). However, the two regression lines intersect at 2 cm total length and they lie so closely together between 2 and 6 cm total length that fish in this size range cannot be assigned to either species with confidence as individual variations can cause overlap in widths.

Since no suitable method was available for positive identification of live fish less than 6 cm total length, I had to rely upon subjective methods based on experience gained from examining large numbers of juvenile flounder. A check was made midway through the study to examine the accuracy of identification. One hundred small juveniles were captured, visually identified, and identifications checked against Manikiam's characters with 91% correct identification being achieved.

3. LARVAL SAND FLOUNDER

3.1 Introduction

Relatively little is known about the biology of the larval stages of sand flounder Rhombosolea plebeia. Most of the literature on this species is concerned with adult fish, although information on the egg and yolk sac stages have been published recently (Robertson and Raj, 1972).

Thomson and Anderton (1921) and Gorman (1960) postulate that sand flounder do not spawn in very shallow water. Colman (1973) found that they spawned in 10-40 metres in the Hauraki Gulf. Mundy's (1968) findings support these views and he indicates that this species does not spawn in the Avon-Heathcote Estuary. The Estuary is thus dependent upon pelagic eggs, larvae or young metamorphosed fish from deeper offshore waters for population recruitment. The problem then arises as to how and when these young stages enter the Estuary?

Mundy (1968) indicates that the principal spawning grounds for sand flounder are the Flounder Patch, covering some 130 km^2, situated between 16 and 36 m depth of water off the Waimakariri and Ashley Rivers; and the Winter Ground, an area of some 65 km^2 situated approximately 32 km S.S.E. of Timaru in 32-45 m of water (Fig. 6). Mundy states that "the Winter Ground is the most important spawning area. The eggs are pelagic (Thomson and Anderton, 1921) and could be carried northward from this region by the Southward Drift Current. Allowing a rate of movement between 6.4 and 16.1 km per day (Brodie, 1960), eggs and larvae spawned on the Winter Ground should cover the 113 km to

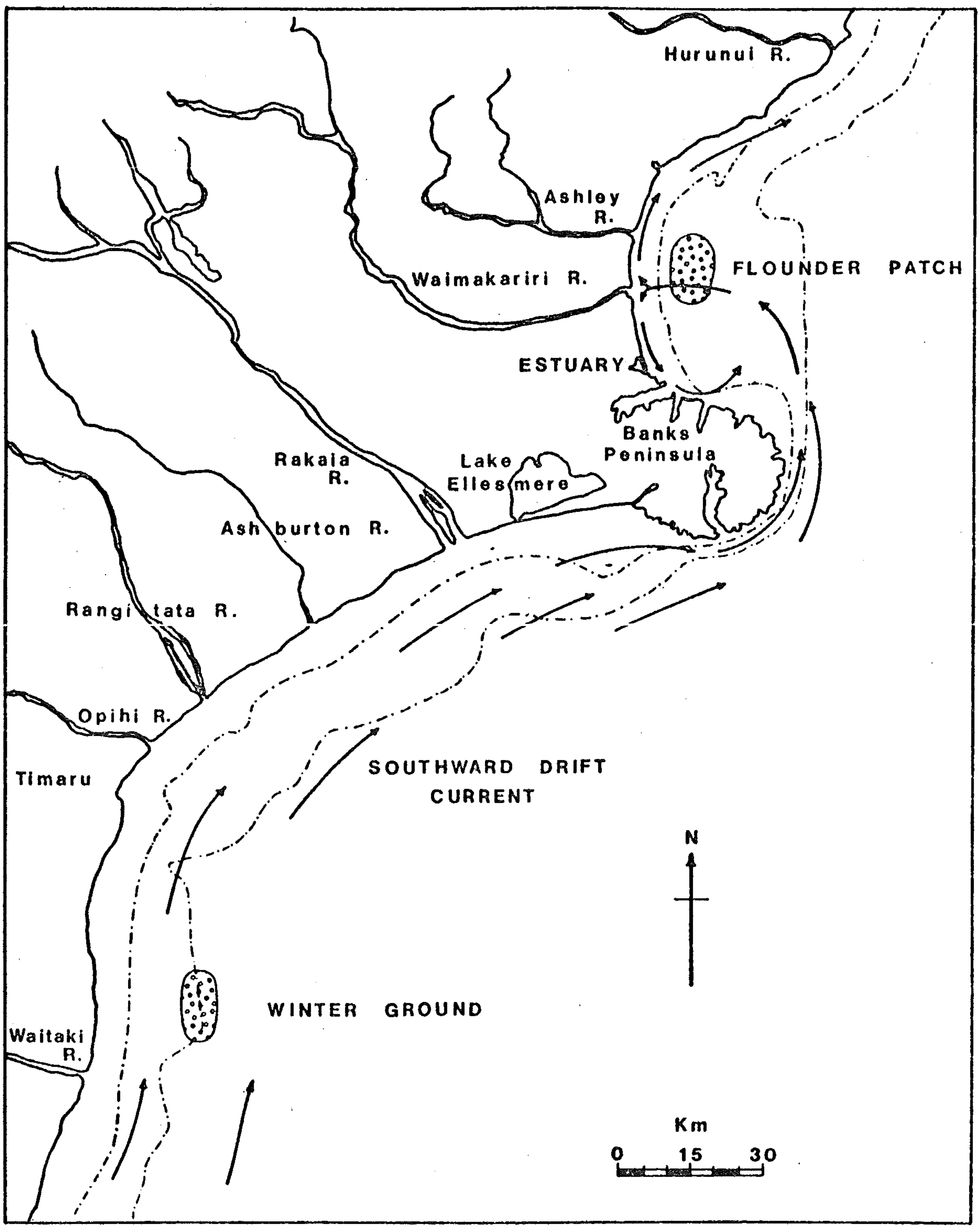


Fig. 6: Location of the principal spawning grounds (Flounder Patch and Winter Ground) of sand flounder, and the current patterns off the east coast of Canterbury (after Mundy, 1968).

Banks Peninsula within 7 to 18 days........By virtue of the fact that this current passes to the north of Banks Peninsula, striking the coastline at Amberley, and sending a branch southwards into Pegasus Bay, eggs or larvae would be carried into the Estuary........" This south branching current system in Pegasus Bay has been accepted by a number of investigators (Dendy, 1897; Gibbs, 1928; Thompson, 1930; Dawson, 1954), and would also serve to bring eggs from the Flounder Patch into the Estuary.

The development of the egg from fertilization to hatching of the larvae is approximately 5 days (Thomson and Anderton, 1921). Therefore it is probable that post-larvae arriving at the Estuary were spawned at the Winter Ground, and eggs or newly hatched larvae at the Flounder Patch.

The present study was mainly a qualitative investigation to determine at what time of year eggs and larvae entered the Estuary. This information was required to assess the effect of the proposed barrier as a physical obstruction to these immigrations.

3.2 Methods

Biweekly collections made from June to December, 1970 with a plankton net (Plate 4) formed the basis of the study. The net was 50 cm diameter and the aperture size of the mesh was 0.22 mm. This mesh was selected to prelude escapement of eggs or small larvae. On a few tows a calibrated flow meter was mounted in the centre of the net opening, and the column of water filtered was calculated from the area of the opening and the measured flow passing through the meter. Horizontal tows were made in the upper metre of water (surface tows), while mid- and bottom-water tows were achieved by attaching weights to the bridle of the net. Bottom tows were soon abandoned because of underwater snags.

A system of standard tows were instituted. Tows lasted 15 minutes and were carried out over a known distance during the flood tide. Current velocity on the ebb tide reaches a maximum velocity of about 1.8 m/sec which would restrict the entry of planktonic animals. The tows were taken in the same direction as the current but at a slightly greater velocity than that of the current so that the net effectively filtered water at a low velocity. The flood velocities of 1.5 m/sec were too high for effective filtering with a stationary net.

Plankton collections were preserved in 5% formalin, and eggs and larvae sorted from the samples and counted. Identification of the eggs was based on Thomson and Anderton's (1921) description which states that the eggs are 0.65 mm diameter and contain 8-13 oil globules. Identification of larvae was aided by a series of photographs showing larval development which were kindly supplied by Dr J.A. Colman, Fisheries Research Division, Wellington.

The stages of larval development identified were those suggested by Dr Colman (pers. comm.). They were:

Stage 1. Yolk sac still present

Stage 2. Yolk sac reabsorbed. Notochord still straight. Pigment developing over anterior half of the body. Fin ray rudiments not yet visible in the tail.

Stage 3. Eyes still symmetrical. Fin ray rudiments now visible. Notochord may be beginning to turn upwards at tail.

Stage 4. Eyes asymmetrical but still on opposite sides of the head.

Stage 5. Eyes on same side of head.

Footnote: Since the field work of the present study was completed, Robertson and Raj (1972) and Colman (1973) have published more information on the egg and yolk sac stages. This information has confirmed that the identification of eggs and larvae during the study was correct. Robertson and Raj redescribed the eggs stating that they may contain 3-15 oil globules, and Colman has given the mean diameter as 0.62 mm (range 0.58 - 0.70 mm) and the number of oil globules as 3-15.

3.3 Results

Large amounts of detritus were collected along with the plankton, and the problem of separating relatively few fish eggs from this detritus led me to concentrate on studying the larvae. The amount of algae and detritus in the samples precluded more than one sample being analysed for each depth on any day because of the considerable expenditure of time in sorting samples in the laboratory when other aspects of the study required attention. Also debris often clogged the mesh and prevented effective filtering of the water. It also affected the use of the flowmeter by frequently jamming the propeller.

Results of the plankton trawls are presented in Table 2. Larvae were present in the plankton samples for 5 months, July to November 1970. Only one larva was captured during daylight. Larvae were captured at all depths, no preferred depth was apparent from the results obtained.

Table 2: Plankton tow records for larval sand flounder

Date	Hours of daylight		Hours of darkness		
	Surface	Mid-water	Surface	Mid-water	Bottom-water
13/ 6/70	0	0	-	-	-
27/ 6/70	-	-	0	0	0
11/ 7/70	-	-	4	1	-
28/ 7/70	-	-	10	7	-
30/ 7/70	0	0	-	-	-
6/ 8/70	0	0	-	-	-
10/ 8/70	-	-	11	-	-
13/ 8/70	-	-	16	0	-
18/ 8/70	0	0	-	-	-
24/ 8/70	-	-	(1), 9	2	2
7/ 9/70	-	-	1	4	(5),19
10/ 9/70	-	-	8	9	-
28/ 9/70	(1)	-	-	-	-
5/10/70	-	-	4	-	-
22/10/70	-	-	3	1	-
6/11/70	-	-	1	2	-
19/11/70	-	-	1	-	-
7/12/70	-	-	0	0	-
22/12/70	-	-	0	0	-

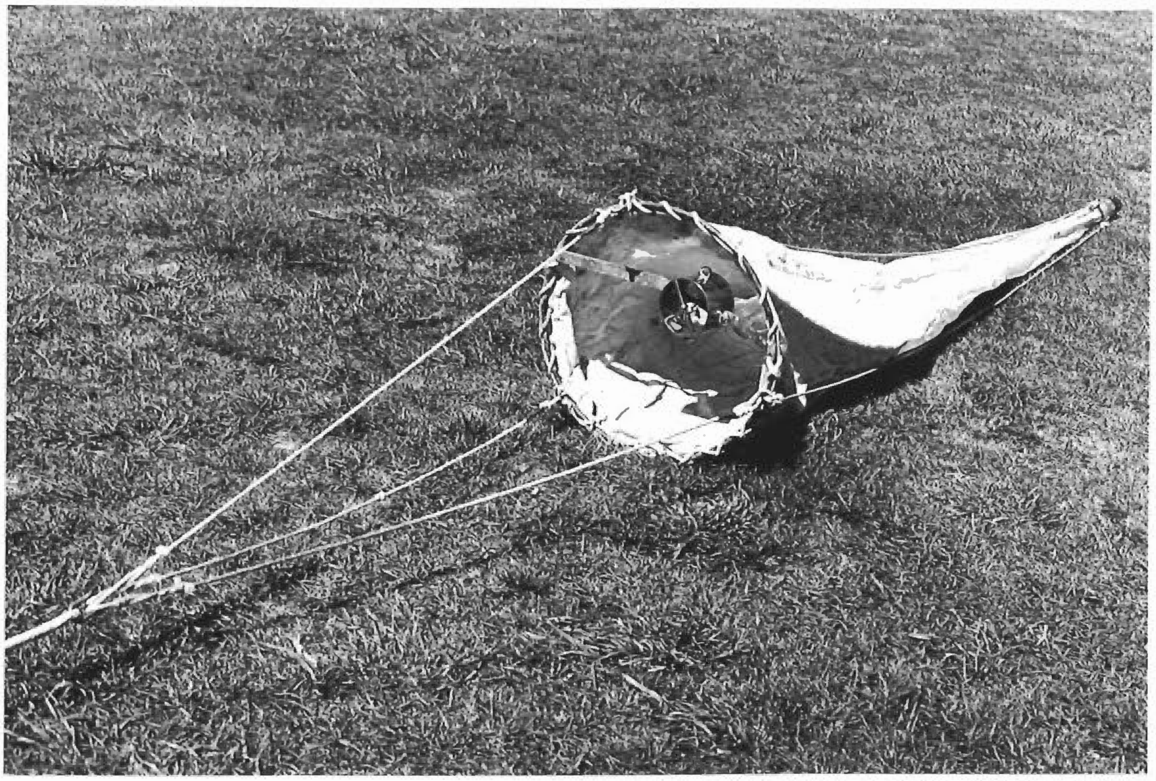
A dash indicates that no sample was collected. Numbers enclosed in brackets indicate Stage 3 larvae, all other numbers refer to Stage 4 and 5 larvae.

Plate 4: Plankton net.

Photo: H. Best.

Plate 5: Larval sand flounder (5.9 mm total length), showing stage of development when recruited to the Estuary.

Photo: H. Best.



3.4 Discussion

Sampling was carried out from June to December, the months in which Mundy (1968) captured ripe fish offshore. No larvae were captured in June or December and it is probable that the majority of larvae entered the Estuary between July and November.

Very few sand flounder eggs were positively identified amongst the detritus in the plankton, although it is probable that spawning on the nearby Flounder Patch results in eggs or young larvae being carried into the Estuary. The symmetrical larvae captured probably originated from this source, and the non-symmetrical larvae from the Winter Ground. The latter larvae appear to be at a state of development suitable for bottom life as they have a flattened shape with a well developed pigmentation pattern and the left eye has migrated to the upper surface indicating that an advanced larval stage is found (Plate 5). Entering the Estuary at an advanced stage may have definite advantages for larvae as it may allow them to settle immediately in favourable areas and so overcome the problem of being transported seawards on the ebb tide. On the other hand non-advanced larvae may not be able to settle and it seems probable therefore that advanced larvae from the Winter Ground will have a better chance of surviving than eggs and larvae from the Flounder Patch. If larvae return to their respective spawning grounds as adults, then the greater survival of advanced larvae producing more adult fish may be an explanation for the "Winter Ground being the more important spawning area, based on the larger numbers of spawning fish being landed in this area" (Mundy, 1968). This is assuming that the Estuary is one of the more important nurseries for sand flounder on the east coast of the South Island.

No indication of vertical stratification in the water column in the lower Estuary was apparent. Water entering the Estuary crosses a shallow bar at a relatively high velocity so that larvae are probably randomly distributed through the water column by turbulence.

Few larvae were caught in daylight tows. This lack of success may indicate that larvae have a photonegative reaction and do not occur high enough up in the water column at sea to be carried into the Estuary during daylight. A more probable explanation is that larvae actively avoid the net. Differences in day and night catches of other fish larvae have been attributed to visual net avoidance (Bridger, 1956; Ryland, 1963) and catches made with slow moving nets are probably not good indications of abundance (Clutter and Anraku, 1968; Noble, 1970). Also, the catches, both at night and day were affected by clogging of the net with detritus.

August-September appears to be the time of peak numbers of larvae entering the Estuary. The volume of water entering on the flood tide is about 7,786,000m^3 (Mawson, 1972) and about 28 flood tides occur at night alone in an 8 week period. Therefore millions of larvae are probably entering the Estuary at this time.

Assuming that the proposed barrier is closed for periods of only 2-3 days, it is unlikely to disrupt the sand flounder life cycle. Such short periods of closure would be insignificant if huge numbers of larvae are entering for some larval immigration continues for five months. Prolonged closure affecting the life cycle can be seen in Lake Ellesmere where infrequent opening of the spit to the sea, often at the wrong time of the year for larval immigration, results in large fluctuations from year to year of flounder catches (New Zealand Marine Department, Report on Fisheries 1944-1972).

4. LENGTH FREQUENCY DISTRIBUTION

4.1 Introduction

Length frequency distributions are analysed in fish studies to age populations, indicate migratory patterns and provide information on growth rate and relative abundance of year classes.

Mundy (1968) determined size-age relationships of sand flounder Rhombosolea plebeia inhabiting the Banks Peninsula region, his age determinations being based on interpretation of seasonal markings on otoliths with supporting evidence from length frequency analyses. His results were used in the present study since his sampling area included the Avon-Heathcote Estuary.

Petersen's (1894) method of age determination is based on a population of fish having a series of discrete age groups with the size range of each age group tending to be distinct from that of adjacent groups and this may be indicated by a mode in a length frequency distribution. The modes of successive age groups become separated along the length axis to give a multi-modal curve, the separate modes representing the approximate mean size of each constituent age group. The age groups are usually not as discrete as one would hope for a number of reasons:

a) Two or more modes per age class are found when spawning occurs more than once each year.

b) Age classes may not be normally distributed in lengths of fish because of prolonged spawning seasons, selection by fishing gear and sexual dimorphism in growth rates.

c) Older age classes may be unrecognizable because they tend to be fewer in number and therefore small samples are obtained. In older age classes the modes tend to overlap as there is a decrease in growth rate with age and the the growth rate also becomes more variable with age.

Some of these limitations do not apply to the present study as it was confined to the first year of life, and most of the problems in recognizing modes are associated with older age classes.

The monthly catches obtained from the Avon-Heathcote Estuary were analysed to provide information on age, growth rates, migratory patterns and the time of entry of newly settled 0+ sand flounder into the population.

4.2 Methods

All sand flounder were measured alive or freshly dead in the field to overcome the problem of shrinkage after death (Mundy, 1968). The 0+ fish were then used for a variety of purposes; some were preserved in 10% formalin for gut and length:weight analysis, others were used in salinity and marking experiments and the remainder were released.

The measurement used in this study was total length (TL) measured to the nearest millimetre from the tip of the closed mouth to the end of the longest caudal fin ray stretched out posteriorly.

Length frequencies were determined for the 0+ age group only. The length to which 0+ fish grow was determined by Mundy (1968). He established that the observed and calculated values for l_t (where l_t = length at age t) from the modified Bertalanffy (1938) equation were 12.0 and 13.4 cm respectively when $t = 1$. For convenience fish less than 13 cm were considered justifiable as a useable method was required for ageing fish in the field.

For length frequency data to have validity the sample taken must be as representative of the population as possible. Some preliminary mesh size experiments were therefore undertaken to ascertain the efficiency of various fishing gear in providing representative samples of 0+ fish. Small nets of 1.27 cm ($\frac{1}{2}$ in) and 3.18 cm ($1\frac{1}{4}$ in) stretched mesh were constructed and fitted to the beam trawl. The standard technique used is to tow the nets to be evaluated together in parallel tows but as the boat and motor available were not capable of doing this, separate tows over a parallel course for each net were made. The catches for each net were individually analysed (Fig. 7) and some statistical parameters obtained from these distributions are presented in Table 3.

Table 3: Statistical parameters (in centimetres) derived from the length frequency distributions in Fig. 7. ($\bar{x}$ = mean, S.E. = standard error of the mean, S.D. = standard deviation and ts = Student's t value)

Mesh size	N	$\bar{x}$	S.E.	Median	S.D.	K-S DMAX	ts
1.27 cm	108	6.86	0.282	5.8	2.934	0.153	> 6.54*
3.18 cm	83	9.52	0.283	9.6	2.582	0.061	

K-S DMAX (see Appendix 1) was not significant indicating that neither distribution differed significantly from a normal distribution.

* Significant difference between means at 1% level.

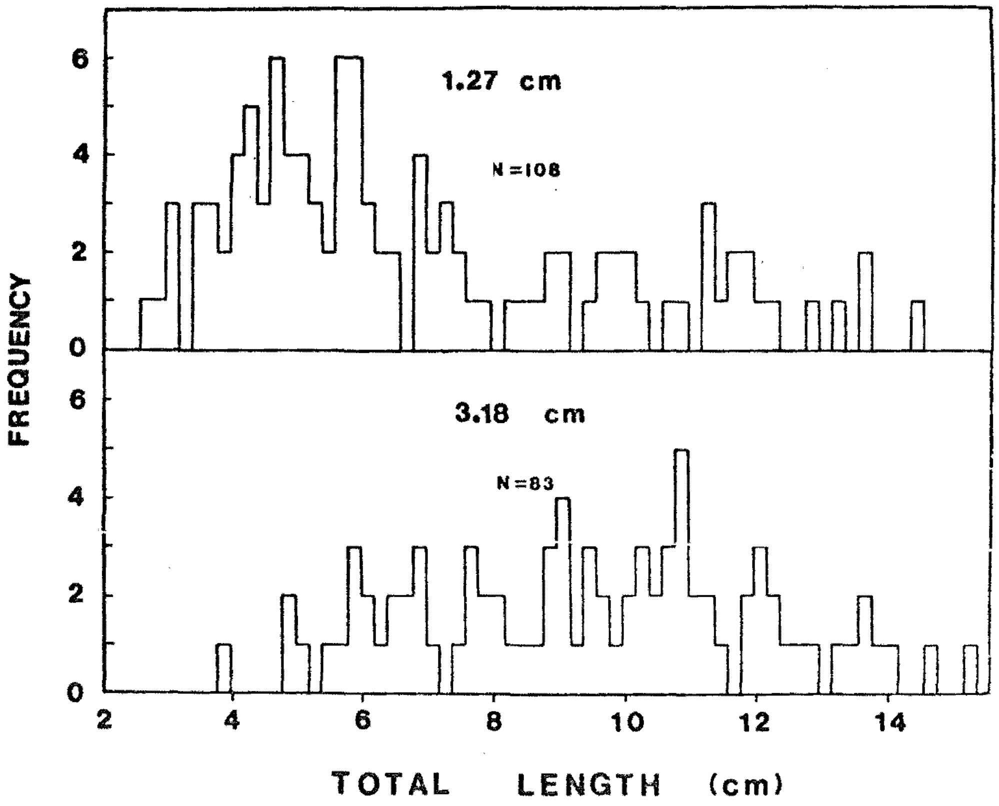


Fig. 7: Length frequency distributions for 0+ sand flounder captured with the beam trawl using 1.27 and 3.18 cm stretched mesh.

Students t-test indicates that the means of the 1.27 cm and the 3.18 cm mesh catches were significantly different. The 3.18 cm mesh catches are large 0+ fish and small 1+ fish, whereas 1.27 cm mesh captured a proportion of smaller 0+ fish which were not caught by the 3.18 cm mesh. The data indicates that escapement of fish less than 6 cm TL may occur with the 3.18 cm mesh (Fig. 7). When a large proportion of very small 0+ fish are present in the population then the 3.18 cm mesh would be ineffective in catching a representative sample. As a result of this test, sampling was undertaken at monthly intervals between April 1970 and March 1971 using the 1.27 cm stretch mesh.

4.3 Results and Discussion

Monthly length frequency distributions for 0+ sand flounder are presented in Fig. 8.

By visual inspection of the distributions, progressive movement along the x-axis of the 0+ mode from month to month can be observed. This is very easily observed from April to July. From July to November settlement of post-larvae occurs (see Chapter 3), and in and after August a new mode is apparent as these newly settled fish grow large enough to be captured by the 1.27 cm mesh. Therefore from August to October two modes are apparent in the size distribution. The larger mode disappears in November-December as these fish are recruited into the 1+ age class and become too large to be captured by the 1.27 cm mesh.

The presence of a bimodal 0+ length frequency distribution is a result of the prolonged spawning season, and this bimodal distribution is partly responsible for difficulties in ageing older age classes by the above method (Mundy, 1968).

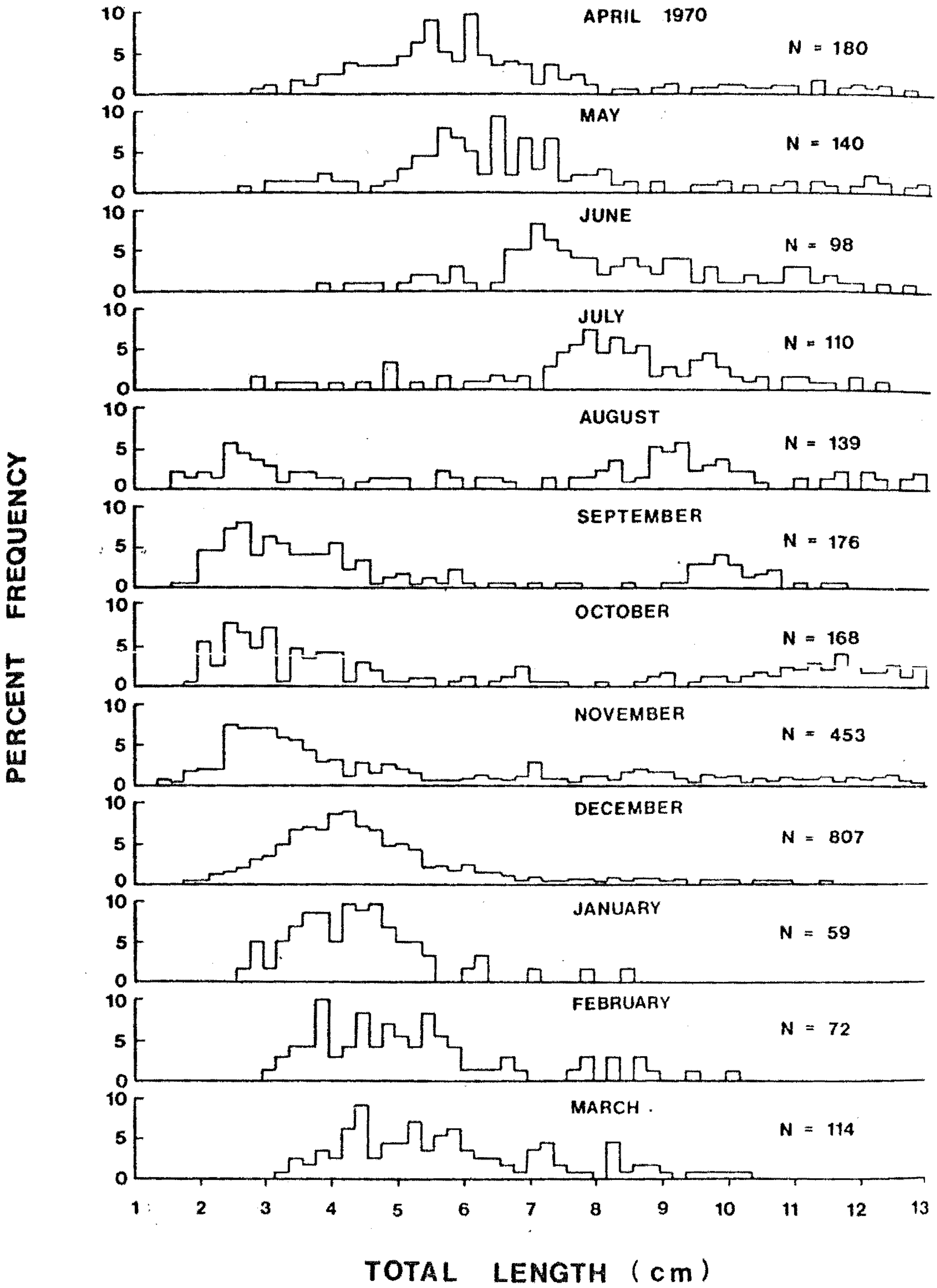


Fig. 8: Length frequency distributions for 0+ sand flounder captured in the Avon-Heathcote Estuary from April 1970 to March 1971.

The 0+ fish leave this age class in November and December the same months that fish entered the 1+ age class in Lyttelton and Akaroa Harbours (Mundy, 1968).

The extended spawning season tended to produce distributions which were not normally distributed (see Fig. 8 and Table 4),

Table 4: Statistical parameters (in centimetres) derived from the length frequency distributions in Fig. 8.

Month	N	$\bar{x}$	S.E.	Median	S.D.	K-S DMAX
April	180	6.33	0.157	5.85	2.102	0.159*
May	140	6.81	0.190	6.40	2.250	0.150*
June	98	8.11	0.194	7.80	1.921	0.074
July	110	8.36	0.207	8.30	2.174	0.119
August	139	7.00	0.289	8.10	3.406	0.130
September	176	5.15	0.235	3.80	3.112	0.223*
October	168	6.27	0.300	4.00	3.887	0.232*
November	453	5.24	0.146	3.80	3.105	0.198*
December	807	4.55	0.052	4.30	1.473	0.132*
January	59	4.46	0.159	4.30	1.222	0.136
February	72	5.37	0.199	5.00	1.688	0.155
March	114	5.95	0.166	5.65	1.711	0.117

* Significant at 1% level indicating data is not normally distributed.

only half of the 12 monthly distributions were normally distributed. The use of Student's t-test to compare these distributions is not appropriate as the test depends on the data being normally distributed. Therefore it was decided to distinguish the two components in the 0+ age class by use of Bhattacharya's (1967) method. The growth of fish in the two components, small fish of the present spawning season and larger fish of the previous spawning season, can be clearly seen (Fig. 9A).

The ease of tracing the growth of 0+ fish by following the modes in Fig. 8 is the result of growth being more rapid in the first year of life. Mundy (1968) showed that sand flounder grow 12 cm in the first year but only 3.8 cm in the sixth year (Fig. 9B). Thus the modes for 0+ fish separate clearly from month to month. Of the many investigations of fish that have been made most have shown that only the first two age classes have distinct visual modes (Cassie, 1956; Halliday, 1969).

The 0+ sand flounder are most abundant in October to December when recruitment to the population is occurring. A gradual decrease in numbers through mortality was found towards winter. Relative abundance of sand flounder was not reflected by the total numbers captured each month. Sampling problems (eg. shifting channel positions, the summer abundance of algae) prevented effective fishing for many months. No method was satisfactorily devised to compensate for the changes in these variables so that catch per unit effort could be standardized. Webb (1966) found a different pattern of sand flounder abundance in his study in the Estuary. He noted a "winter abundance with a decline in numbers in the summer months". However, he used 5.08 cm mesh so that he was mainly capturing 1+ and 2+ age class. The decrease he noted in the summer would largely be due to the emigration of 1+ and 2+ fish out to sea as shown by Mundy.

Length frequency distributions of sand flounder captured in some pools exposed at low water on the mudflats at Station 3

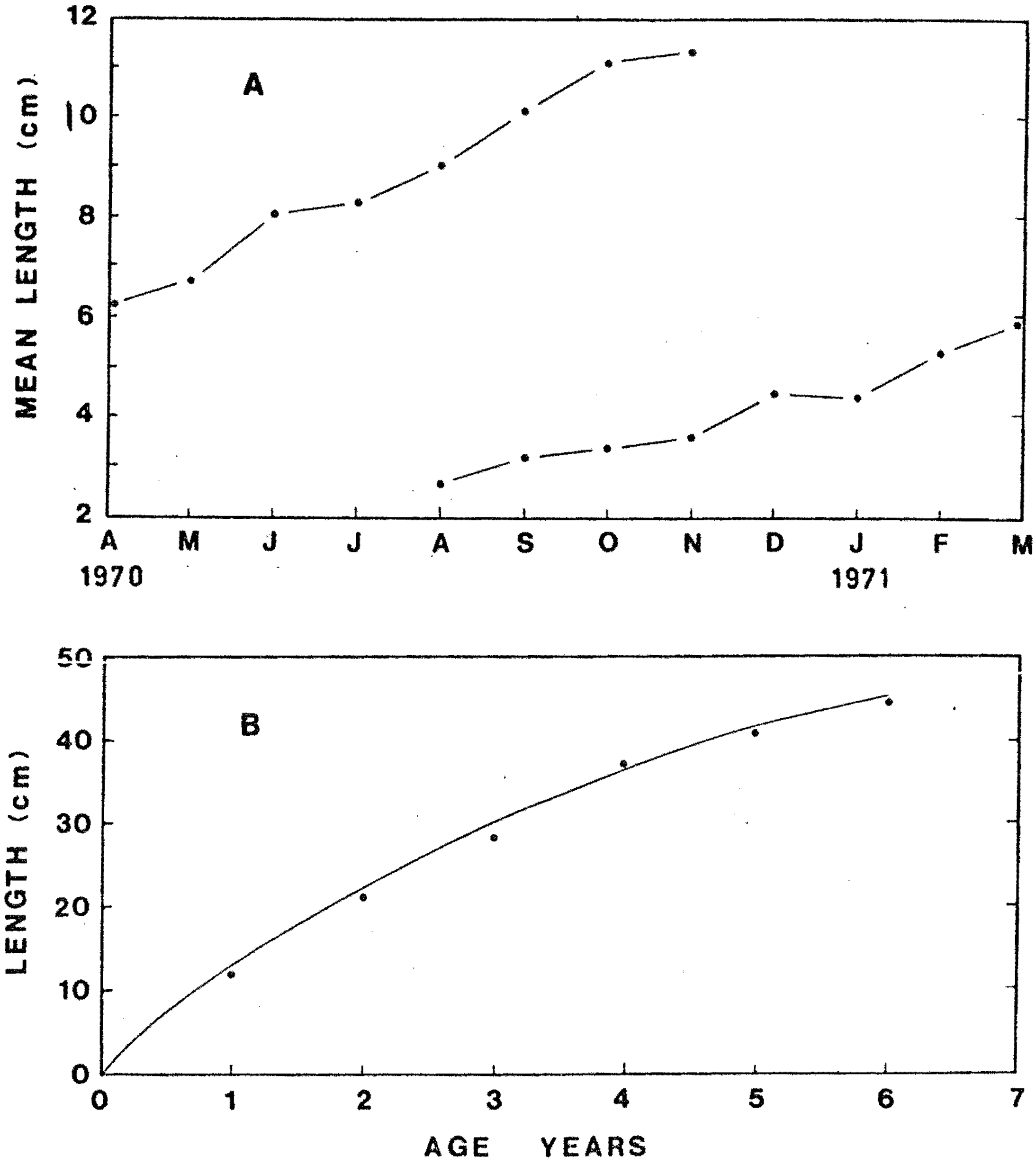


Fig. 9A: Mean lengths of the two components in 0+ age class of sand flounder.

Fig. 9B: Growth curve for sand flounder (after Mundy, 1968).

were also analysed (Fig. 10). The distributions were normally distributed and therefore Student's t-tests could be used to show that a trend was apparent for significant increase in mean length between successive months (Table 5). With increasing

Table 5: Statistical parameters (in centimetres) derived from the length frequency distributions in Fig. 10.

Month	N	$\bar{x}$	S.E.	Median	S.D.	K-S DMAX	ts
October	98	1.67	0.049	1.6	0.487	0.151	
							5.16**
November	91	2.09	0.065	2.0	0.623	0.133	
							2.25*
December	110	2.28	0.052	2.2	0.550	0.104	
							7.45**
January	116	2.85	0.055	2.7	0.596	0.110	

* Significant difference at 5% level, ** significant difference at 1% level.

size sand flounder are no longer caught in the pools and they probably migrate into the deeper water of the mudflat streams. The fish were captured from these pools using a one millimetre mesh hand net and therefore these samples cannot be directly compared with those obtained with the beam trawl. However, field observations indicated that small fish are characteristically found in these pools. The differences in mean lengths of fish found in different habitats are associated with changing tolerances to a number of factors such as salinity and current velocity (see Chapter 7).

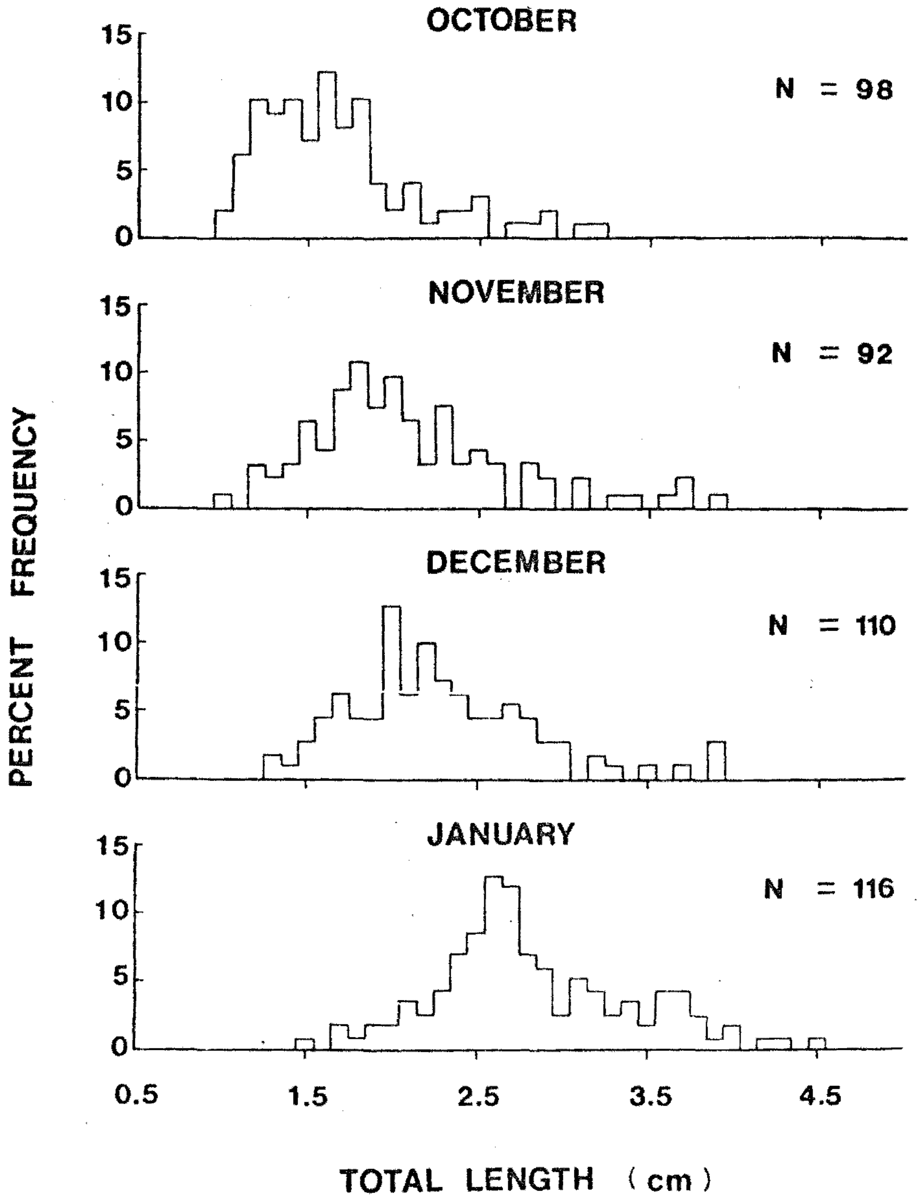


Fig. 10: Length frequency distribution of 0+ sand flounder captured in mudflat pools at Station 3 between October 1970 and January 1971.

4.4 Summary

Preliminary mesh size experiments showed that the 3.18 cm mesh undersampled the smaller 0+ sand flounder; escapement of fish less than 6 cm occurred. A 1.27 cm mesh caught a more representative sample of 0+ fish.

The catch per unit effort varied widely from month to month so that the total numbers captured each month does not necessarily reflect abundance. Nevertheless, 0+ sand flounder tended to be more abundant in October to December, the period over which they were recruited into the population as newly settled fish.

Monthly length frequency observations were carried out using 2,516 0+ sand flounder from April 1970 to March 1971. Visual appraisal of the length frequency modes and statistical analysis of these length frequencies provided evidence for : growth of the 0+ fish during the 12 month period, the time of settlement of post-larvae and recruitment of the newly settled fish into the sample, and the migration of 0+ fish into different habitats with growth.

5. LENGTH : WEIGHT RELATIONSHIP

5.1 Introduction

"The analysis of length:weight data has usually been directed towards two rather different objects. First, towards describing mathematically the relationship between length and weight, primarily so that one can be converted into the other. Secondly, to measure the variation from the expected weight for length of individual fish or groups of individuals as indications of fatness, general 'well being' ...." Le Cren (1951). The term 'length:weight relationship' is applied to the first category, and the term 'condition' to the second category. Changes in weight for length (or condition) are due to changes in form or volume and not in specific gravity as the density of the fish as a whole is maintained the same as that of the surrounding water by the swim bladder except in completely demersal fish (Le Cren, 1951). These factors have been investigated for 0+ sand flounder Rhombosolea plebeia.

Fish studies aim at obtaining growth rates in relation to fish length using otoliths, scales or skeletal structures for ageing. In these studies the length:weight relationship is then established so that growth can then be determined in terms of weight. Weight at age curves can then be obtained. Fish growth typically involves an initial period of rapid increase in length followed by a period of slower increase. The initial rapidly increasing phase is limited to the first two years of life (Graham, M., 1956). The growth beyond the point of inflexion has been successfully represented for a large number of fish species by the von Bertalanffy (1938) growth equation. The parameters involved may be estimated graphically and a growth plot obtained by using an expression developed by Ford (1933) and Walford (1946). Such growth equations were not suitable for use in the present study as they describe growth in successive years during the life of a fish. Whereas this study was directed towards growth during the first year of life in sand flounder. Growth over successive years in sand flounder has been investigated by Mundy (1968). In the present study length: weight data ~~was~~ were used principally for indicating condition so that the relationship between condition and the breeding and feeding cycles could be established.

5.2 Methods

About 20 age 0+ sand flounder were obtained from both Stations 3 and 5 (Fig. 1) at bimonthly intervals between March 1970 and February 1971. The total length of each fish was measured (to the nearest millimetre) from the tip of the closed mouth to the end of the longest caudal fin ray stretched out posteriorly. These lengths were measured while the fish were alive or freshly dead to overcome the problems of shrinkage described by Mundy (1968). Wet weight was measured to 0.01 grams on a Mettler Balance, excess water being removed immediately prior to weighing. Alimentary tracts were removed (for gut content analysis) and the fish reweighed. These eviscerated weights were used for analysis of length:weight relationships as varying amounts of gut contents are a potential source of error.

Length and weight parameters were analysed using Bartlett's

(1949) three-group method since both variables are subject to error in measurement.

5.3. Results and Discussion

Length:weight relationships of most fish can usually be described by a formula of the type:

$$W = a\ L^{b}$$

where W = weight, L = length, a is a constant and b an exponent. The bimonthly length:weight relationships were computed and are presented in Table 6. A b coefficient of 3.0 characterizes

Table 6: Length : weight relationships of 0+ sand flounder (weight in g and length in cm). Relationships are of the form log W = a + b log L.

	Month	N	Coeff.a	99% CL	Coeff.b	99% CL
Station 3	Mar.	38	-2.115	0.020	3.047	0.098
	May	32	-1.930	0.016	3.037	0.079
	Jul.	37	-1.960	0.014	3.052	0.082
	Sep.	20	-2.088	0.024	3.211**	0.144
	Nov.	20	-2.118	0.018	3.102	0.085
	Jan.	30	-2.281	0.036	3.337**	0.195
Station 5	Mar.	18	-2.004	0.024	3.085	0.089
	May	21	-1.928	0.024	3.050	0.116
	Jul.	20	-1.975	0.023	3.083	0.099
	Sep.	18	-2.025	0.054	3.134*	0.147
	Nov.	20	-2.066	0.020	3.013	0.087
	Jan.	26	-2.036	0.024	3.028	0.134

* Significant deviation from 3.0 at 5% level.
** Significant deviation from 3.0 at 1% level.

a fish having an unchanging body form and unchanging specific gravity ie. growing isometrically. Whereas, when $b > 3$ or $b < 3$ the fish becomes heavier or lighter respectively in relation to its length indicating allometric growth. The b coefficient was significantly greater than 3.0 at the 0.01 probability level in two of six analyses at Station 3 and only significant at the 0.05 probability level in one sample at Station 5. It is evident that the fish in most samples were growing isometrically. The high values of b showing allometric growth occurred in September and January. August to October were the main months when very young fish were recruited into the Estuary population. It is possible that very young fish do not exhibit isometric growth but have a changing body form. No explanation for the January result is apparent.

Analysis of covariance was the used to compare the length: weight relationships found during the year. However, the variances for the regression lines did not comply with the conditions of homogeneity of variances (Bartlett's test of homogeneity of variances) as the chi-square value of 50.08 was significantly greater than $\chi^2_{0.01} = 24.74$ for 11 degrees of freedom. Therefore, use of analysis of covariance on these regression lines was not valid. The January Station 3 and September Station 5 samples had large residual variance (MS) values, indicating that these samples had a larger spread of points from the regression line than the other samples. Each station was then tested separately by analysis of covariance omitting the two samples that did not have homogeneous variances. The two stations were kept separate because it was considered that the result would be suspect if tested for a common regression when a sixth of the samples was omitted. The slopes b were not significantly different within stations as F = 3.93 and F = 0.27 where $F_{0.01}$ (4,137) = 3.94 and $F_{0.01}$ (4,95) = 3.56 for Stations 3 and 5 respectively. However, the points of intercept within stations were significantly different as F = 130.44 and F = 79.05 where $F_{0.01}$ (4,141) = 3.94 and $F_{0.01}$ (4,99) = 3.56 for Stations 3 and 5 respectively. These differences in the points of intercept on the axis can be seen in Fig. 11.

Further analysis using a test for difference between slopes (Simpson, Roe and Lewontin, 1960, p. 237) showed that the two samples without homogeneous variances were not significantly different from the other 10 regression lines (t = -0.516 and 0.163 for January Station 3 and September Station 5 respectively). The reason for the abnormal variances in these two samples is not known although for very small fish the results may be biased as it is more difficult to obtain accurate measurements of length and weight, for instance, excess surface water will cause a disproportionately large error in weight.

The measurement of the variation from the expected weight for length of individuals or groups of individuals are indications of condition (Le Cren, 1951). Le Cren pointed out that when b coefficients do not change significantly between samples then changes in coefficient a can be used to describe the condition of a fish. The analysis of covariance showed that within stations the regression lines had similar b coefficients but significantly different points of intercept, but because of the two abnormal variances differences between stations were not tested. Therefore it is not known if the coefficient a will give a measure of condition that is comparable between the 12 samples.

An alternative approach was therefore adopted, the condition being computed from

$$K_b = \frac{W}{\hat{W}}$$

which was derived by Le Cren (1951) from

$$K_b = \frac{W}{aL^b}$$

where K_b is condition and $\hat{W}$ is the adjusted or smoothed mean weights calculated following the method of Snedecor and Cochran (1967, p. 429). The adjusted mean weights were calculated from a pooled regression of all samples and was not affected by the variation in mean lengths of fish captured in different samples. The condition index thus obtained measures the deviation of an individual from the average weight:length ratio of all fish measured and not the deviation from a hypothetical fish which obeys the cube law. Condition based on a hypothetical fish should not be used as factors such as selection in sampling and genetic racial differences may cause differences in condition to be attributed to environmental factors (Le Cren, 1951).

The computations of K_b are shown in Fig. 12. Both stations exhibited similar seasonal changes, with poor condition in September and November, a period of rapid increase in condition by January and a small decline to a plateau in the following months until July, when presumably the cycle would start again. In the six month period following March the fish at Station 3 appeared to be in better condition than fish at Station 5. This may be correlated with the greater variety of food eaten at Station 3 (see Chapter 6).

It is apparent that the poorest condition was found in

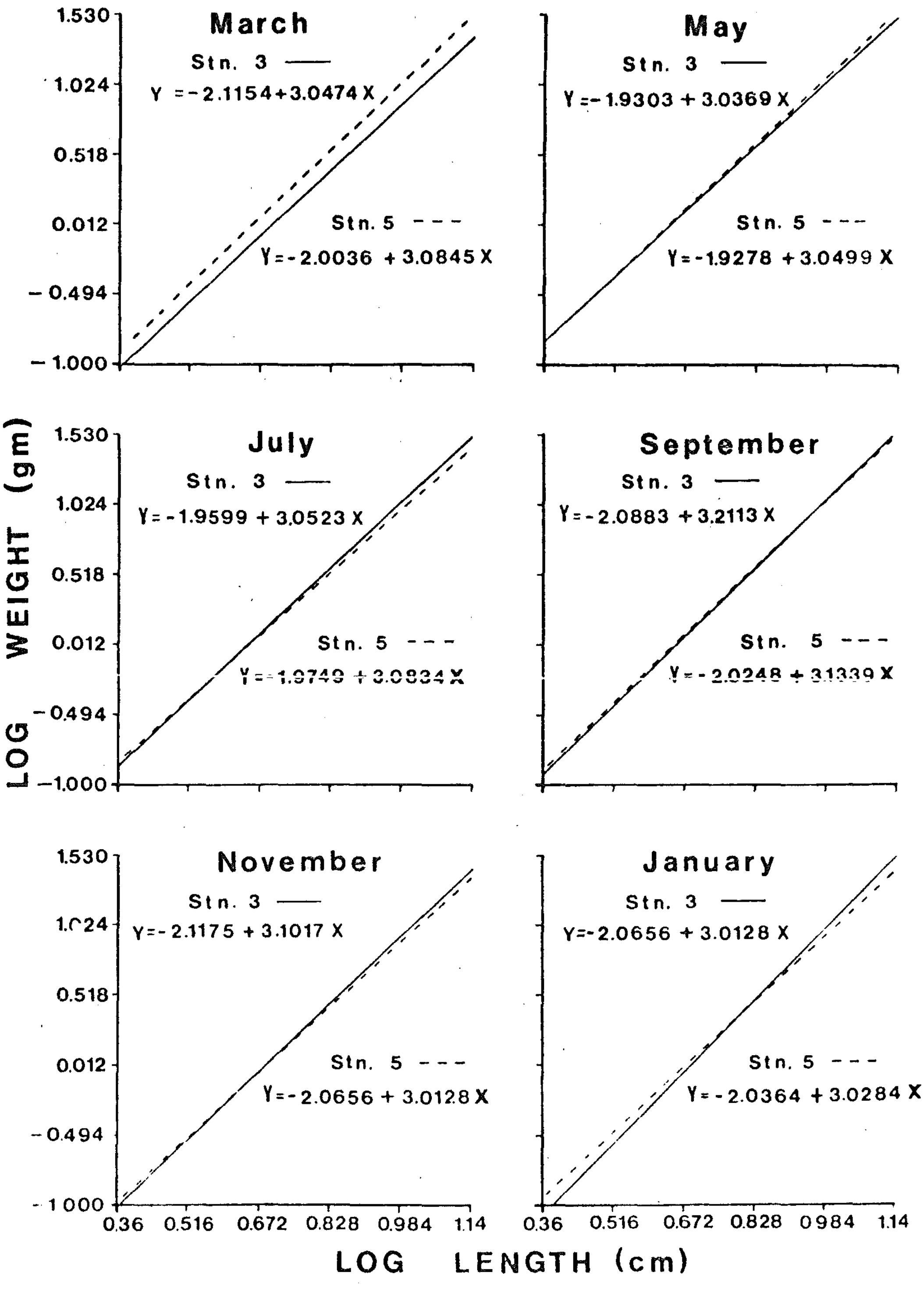


Fig. 11: Length:weight relationships for 0+ sand flounder between March 1970 and January 1971.

the months, September to November, when young fish were being recruited into the population sampled. The young fish have recently changed from living off their yolk sacs to having to fend for themselves. Their growth rate is high and therefore their energy demands are high and perhaps do not allow body reserves to be built up. For very small fish the results may be biased as explained earlier.

The rapid increase in condition of 0+ sand flounder by January follows the general trend found in many fish where condition is generally better in summer, probably because warmer water temperatures result in more abundant food and increased feeding activity. A summer high is often followed by a winter low for converse reasons. The relatively good condition found in the present study during late autumn-early winter may result from a decrease in numbers of fish due to mortality during late summer-autumn, this decline leading to decreased competition for food and space.

5.4 Summary

Length:weight relationships were calculated and for most samples the b coefficient was not significantly different from 3.0 indicating that 0+ sand flounder were growing isometrically. Deviations from 3.0 occurred in samples taken in the months when very young fish were being recruited into the population probably showing that these fish do not have isometric growth.

Condition of 0+ fish showed a marked seasonal cycle with decreased condition in spring and early summer when young fish were being recruited into the population, followed by a rapid

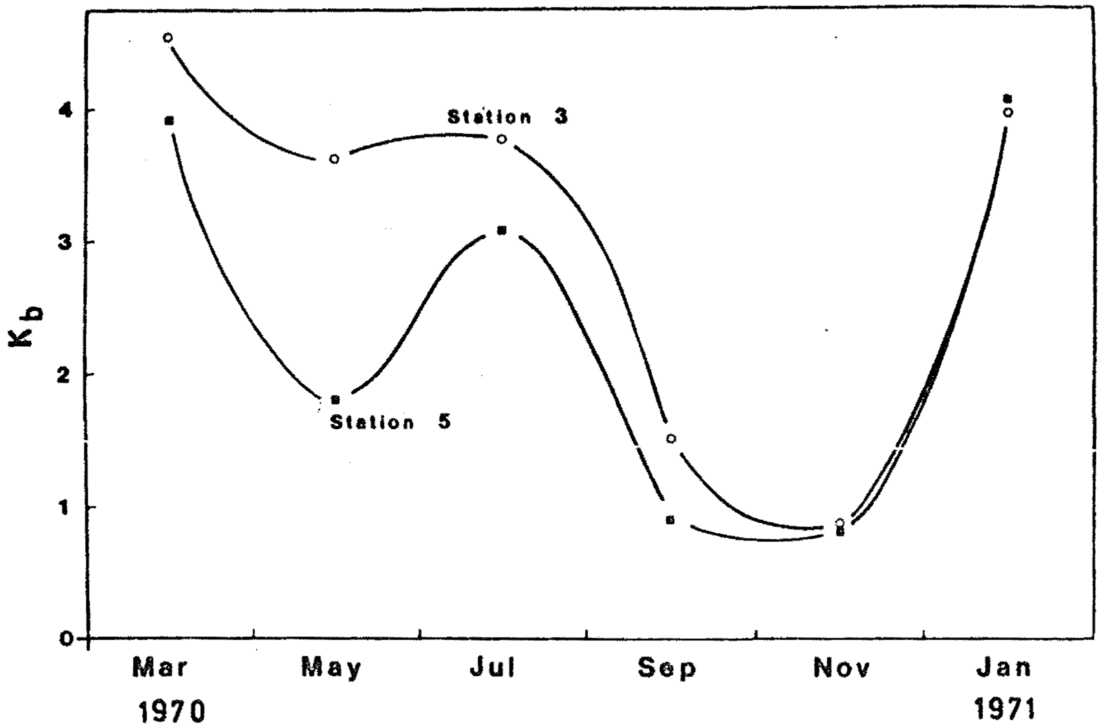


Fig. 12: Seasonal variation in mean values of K_b for 0+ sand flounder captured at Stations 3 and 5.

increase in condition by mid summer and a gradual reduction towards late winter.

6. FEEDING HABITS

6.1 Introduction

The importance of the Avon-Heathcote Estuary in the ecology of 0+ sand flounder Rhombosolea plebeia has been indicated in the previous chapters. The Estuary is densely populated by larval and juvenile sand flounders, their growth is rapid and it is probable that juvenile productivity is high.

The feeding habits of larger sand flounder have been studied in the Estuary and off the Canterbury coast (Webb, 1966, 1973b; Mundy, 1968), but there has been little analysis of juve-mile food habits in an area which is intensely utilized as a nursery. More is known of the juvenile feeding habits of other flatfish species overseas (Steven, 1930; Shelbourne, 1953; Pearcy, 1962; Macer, 1967; Edwards and Steele, 1968; Gibson, 1973).

Webb (1966, 1973b) has obtained some data for sand flounder from the Estuary, but his study included mainly 1+ and 2+ fish and only small numbers of large 0+ fish. The present study therefore complements his study. He found that sedentary poly-chaetes and amphipods formed the bulk of the diet, with bivalves and decapods the next most important in that order. Mundy (1968) obtained feeding data for sand flounder off the Canterbury coast. He showed that juvenile fish in all areas fed largely on amphi-pods with decapods, sedentary polychaetes and cumaceans forming the bulk of the diet of older fish.

In the present study, samples were collected from the Estuary bimonthly from March 1970 to January 1971 to analyse the feeding habits of 0+ sand flounder. Two sampling stations were selected to include a variation in sediments, salinities and pollution effects. The diet was examined for seasonal changes and in relation to changes in the length of fish.

6.2 Methods

Bimonthly samples were obtained by beam trawl from Stations 3 and 5 (Fig. 1). From each station 20 fish of a wide range of sizes were selected and preserved in 10% formalin in the field after their body cavities were cut open to avoid continued digestion.

In the laboratory the fish were measured (total length), and their alimentary tracts were removed under a binocular microscope. Problems were encountered in the analyses because the fish lack a distinct boundary between the stomach and intestine and therefore the contents of the entire alimentary tract had to be examined. This may have resulted in food groups with persistent exoskeletons being overrepresented in relation to soft bodied species. Mundy (1968) noted a similar problem.

The degree of fullness of complete alimentary tracts was determined using Hynes' (1950) method as modified by Thompson (1959). Points were allotted as in Table 7. Thompson stated that "the allottment of the stomach points prior to the evaluation and identification of the food items prevented the possibility of large, relatively undigested items, leading the investigator to overestimate their volumetric importance".

Food organisms were separated into major food categories

Table 7: Points allotted to alimentary tracts of varying fullness.

Number of Points	Fullness of Gut
20	full
15	$\frac{3}{4}$
13	$\frac{2}{3}$
10	$\frac{1}{2}$
7	$\frac{1}{3}$
5	$\frac{1}{4}$
2	trace
0	empty

(e.g. polychaetes, molluscs), and whenever possible specific identifications of organisms was made. Three different statistics outlined by Godfriax (1969) were used to measure food composition.

1. Percent occurrence: obtained by dividing the number of fish containing a given food item by the total number of fish in the sample.
2. Percentage of volume composition: food points allotted as in Table 7 for the relative volume of each food category. These points were summed and divided by the total potential gut volume (number of fish examined multiplied by 20, the value for a full gut). This statistic gives the percentage volume occupied by each food category including the empty volume.
3. Percentage of diet composition: food points for each food category were summed and divided by the total number of food points awarded to all fish in the sample. The considerable volume of gut not occupied by food was ignored in order to convert the food categories into larger percentages to

facilitate easier comparison of their relative volumes.

A points method where food items receive a value in relation to the potential gut volume provides a rapid, useful technique, however the subjective allocation of points is the main limitation of the method. No consideration of comparative sizes of guts was made, as it was assumed that a full stomach is just as important for a small fish as it is for a large fish. As the maximum stretching of gut walls and the capacity of the gut can only be estimated, the allottment of points for degrees of fullness can only be based on experience.

It was considered that displacement volume determined with graduated cylinders would have been a less subjective method than the one used. However a staple part of the diet consisted of polychaetes which were often fragmented and partially digested, and an accurate estimate of volume displacement would not have been possible. For the same reason actual weights of food items, a method proposed by Ricker (1937) was not used. Consideration also of calorific and dietetic values of food items is also desirable (Hynes, 1950), but the examination of such factors was beyond the scope of the present study.

The results obtained in the present investigation were tested for differences in the food eaten between food categories, between stations and between size groups of fish using a R x C contingency test - G statistic (Sokal and Rohlf, 1969; see Appendix 1 for explanation of G statistic). It was assumed that food would be eaten in equal proportions (ie. 1:1, 1:1:1 etc.) and the test determines the goodness of fit of the observed frequency distribution to the expected frequency distribution.

6.3 Results and Discussion

General Pattern of Feeding

The results of gut analyses of 240 0+ sand flounder are shown in Table 8. To aid enumeration of results, food items

Table 8: Diet of 0+ sand flounder

Food Category	Occurrence		Food Point		
	Number	Percent	Number	Percent volume composition	Percent diet composition
1. Empty	11	1.6	2274	47.4	-
2. Sand/mud	211	29.9	952	19.8	37.7
3. Polychaeta	141	20.0	573	11.9	22.7
4. Digested matter	142	20.1	292	6.1	11.6
5. Amphipoda	67	9.5	251	5.2	9.9
6. Decapoda	37	5.2	186	3.9	7.4
7. 'Siphons'	31	4.4	148	3.1	5.9
8. Mollusca	22	3.1	35	0.7	1.4
9. Nemertea	13	1.8	48	1.0	1.9
10. Algae	25	3.5	34	0.7	1.4
11. Miscellaneous	6	0.9	7	0.2	0.3
TOTAL	706	100.0	4800	100.0	100.2

have been grouped into categories on the basis of natural taxonomic groups and according to frequency of occurrence. Only 52.6% of the gut volume was occupied with food, and sand, polychaetes, digested matter and amphipods were the major items in the diet.

In Fig. 13 the three statistics for assessing the composition of food are shown. Much the same order of importance of

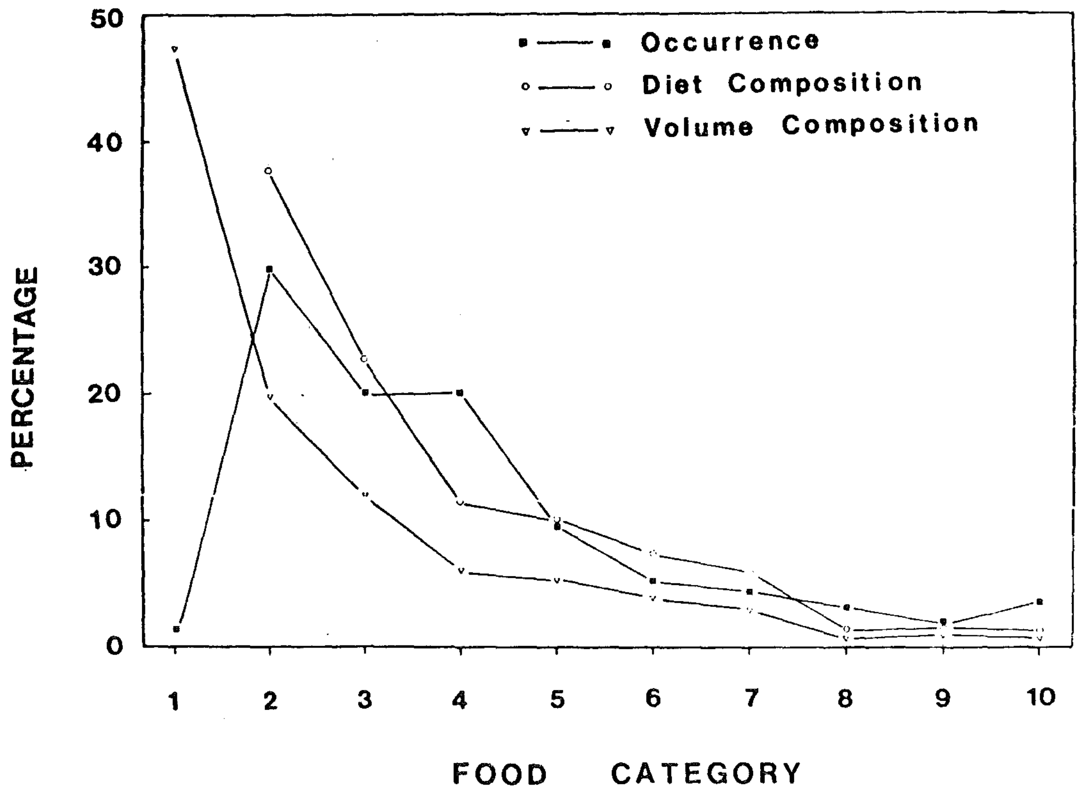


Fig. 13: Comparison of three statistics for measuring feeding of 0+ sand flounder (see Table 8 for key).

food categories are given by volume and diet composition statistics. However, the percent occurrence showed some differences; the volume occupied by amphipods, molluscs and algae was small compared with the number of times they occurred, thus the percent occurrence method exaggerates their importance. The percent occurrence method also underestimated the importance of volume not occupied by food, since the number of completely empty guts was small. As Thompson (1959) comments "a measure of the emptiness of a stomach only partially filled with food is not possible with this method (percent occurrence)". Therefore, in general only diet composition was considered since it appeared to be a better basis for assessment than percent occurrence and also it gave larger percentages for comparison than volume composition.

The following notes on 'food' categories are presented in order of importance in the diet.

Sand: Sand, mud and detritus formed a considerable portion (37.7%) of the diet composition of 0+ sand flounder. Mundy (1968) noted for this species that "quantities of mud and detritus were particularly noticeable in year class 0+ fish", and the presence of these items is probably a consequence of the bottom feeding habit. Mundy suggested that juveniles may take in sand and detritus as a direct source of energy. This explanation is a strong possibility in the Estuary where productivity is high and microorganisms are abundant in the sediment. Also, sand tends to be abundant in the gut because it is indigestible and thus increases in relative abundance down the length of the intestine compared with other food which is more easily digested.

Polychaeta: Polychaeta constituted 22.7% of the diet composition. The principal species eaten in order of dominance were *Boccardia polybranchia* (Haswell), *Nicon aestuariensis* Knox, *Haploscoloplos cylindrifer* (Ehlers), *Aonides trifidus* Estcourt, *Glycera americana* Leidy and *Pectinaria australis* Ehlers.

Most polychaetes were fragmented or in an advanced state of digestion, and it proved difficult to determine the number of individuals involved and their identification. For this reason the number of polychaete species may be low, and it is probable that most of the species found in the Estuary by Estcourt (1962) are utilized at some time by 0+ sand flounder.

Digested Matter: Unidentified well-digested food was present in large quantities (11.6%) because of the tendency for young fish to feed on soft-bodied food which is rapidly digested. The percentage is higher than it would have been if only stomach contents could have been examined as the percentage of digested matter increases with passage down the intestine.

Amphipoda: The amphipod *Paracorophium excuvatum* (Thomson) was a common food item (9.9%).

Decapoda: Crabs contributed 7.4% of the bulk of the food consumed. The important species were *Helice crassa* (Dana) 4.3%, *Hemiplax hirtipes* (Jacquinot) 2.1% and *Hemigrapsis crenulatus* (Milne Edwards) 1.0%. On a few occasions *Halicarcinus whitei* (Filhol) had been eaten.

'Siphons': Siphons of bivalves formed 5.9% of the diet. They were provisionally identified as being from *Chione stutchburyi* Gray and *Macomona liliana* (Iredale). Siphons were an important food and this is similar to Edwards and Steele's (1968) findings that a large part of the predation by young plaice Pleuronectes platessa L. consisted not of consumption of whole animals but of cropping of tips of bivalve siphons and polychaete palps. McIntyre and Eleftheriou (1968) suggested that the rate of regeneration of these organs was of as great importance as production of the whole animal as a source of food for these fish. A similar cropping-production situation may apply in the Estuary.

Mollusca: Molluscs (excluding siphons) formed only 1.4% of the diet. Gastropods contributed 0.5% and were mainly Amphibola crenata (Martyn) and Zediloma subrostrata Gray, although Micrelenchus huttoni (Smith) and Cominella glandiformis Reeve were occasionally eaten. Bivalves formed the other 0.9%; Chione stutchburyi and Macomona liliana being most common, and with Amphidesma australe australe (Gmelin) and Cyclomactra ovata (Gray) also being eaten.

Nemertea: Nemerteans formed 1.9% of the diet. The two species found were not identified.

Algae: The algae Ulva lactuca L., Enteromorpha ramulosa (Kutz) and Gracilaria secundata (May) formed 1.4% of the diet.

Miscellaneous: This category includes some unidentifiable material, as well as the anemone Anthopleura aureoradiata Stuckey and the isopods Metacirolana spp. They formed a total of 0.3% and were not included in Fig. 13.

The presence of sand, polychaetes, amphipods and decapods as the major items in the diet indicate that 0+ sand flounder in the Estuary are bottom feeders. Most investigators have obtained similar results for adult flatfish although this need not have been necessarily true for juveniles. Juvenile winter flounder

Pseudopleuronectes americanus (Walbaum) (Pearcy, 1962) and plaice Pleuronectes platessa L. (Macer, 1967) as well as feeding on infauna and epifauna also fed on plankton, although Macer considered that it was mainly bottom plankton. No plankton was found in 0+ sand flounder.

Seasonal Variation in Feeding

Seasonal variations in diet composition of 0+ sand flounder are shown in Fig. 14. There were significant differences in proportions of sand, polychaetes, digested matter, amphipods and decapods in all months (G values ranged from 16.45 to 116.40 compared with the critical $\chi^2_{0.01}$ value of 13.27).

Polychaetes did not show any seasonal variation however, and were eaten in about equal volumes (20-30%) in each month. There was no seasonal trend in feeding on amphipods, and the amount eaten fluctuated from month to month with no trend being apparent. Bivalve siphons were commonly taken throughout the year at Station 5 only. Decapods were eaten to a significant extent only during summer (January-March).

Seasonal changes in degree of gut fullness are shown in Table 9. Maximum fullness (76.8%) occurred in summer (January-March), fell to a minimum of 39.4% in winter (July-September) and then rose again towards the following summer.

The fullness method for indicating feeding activity has been used by Southern (1935), Frost (1939), Frost and Went (1940), Hartley (1947), Venkataraman (1960) and Halliday (1969), and is based on the assumption that the rate of digestion is constant from season to season. However this need not be so as food items of differing digestibility may occur in the diet in different seasons. Staples (1971) reported for the bully Philypnodon

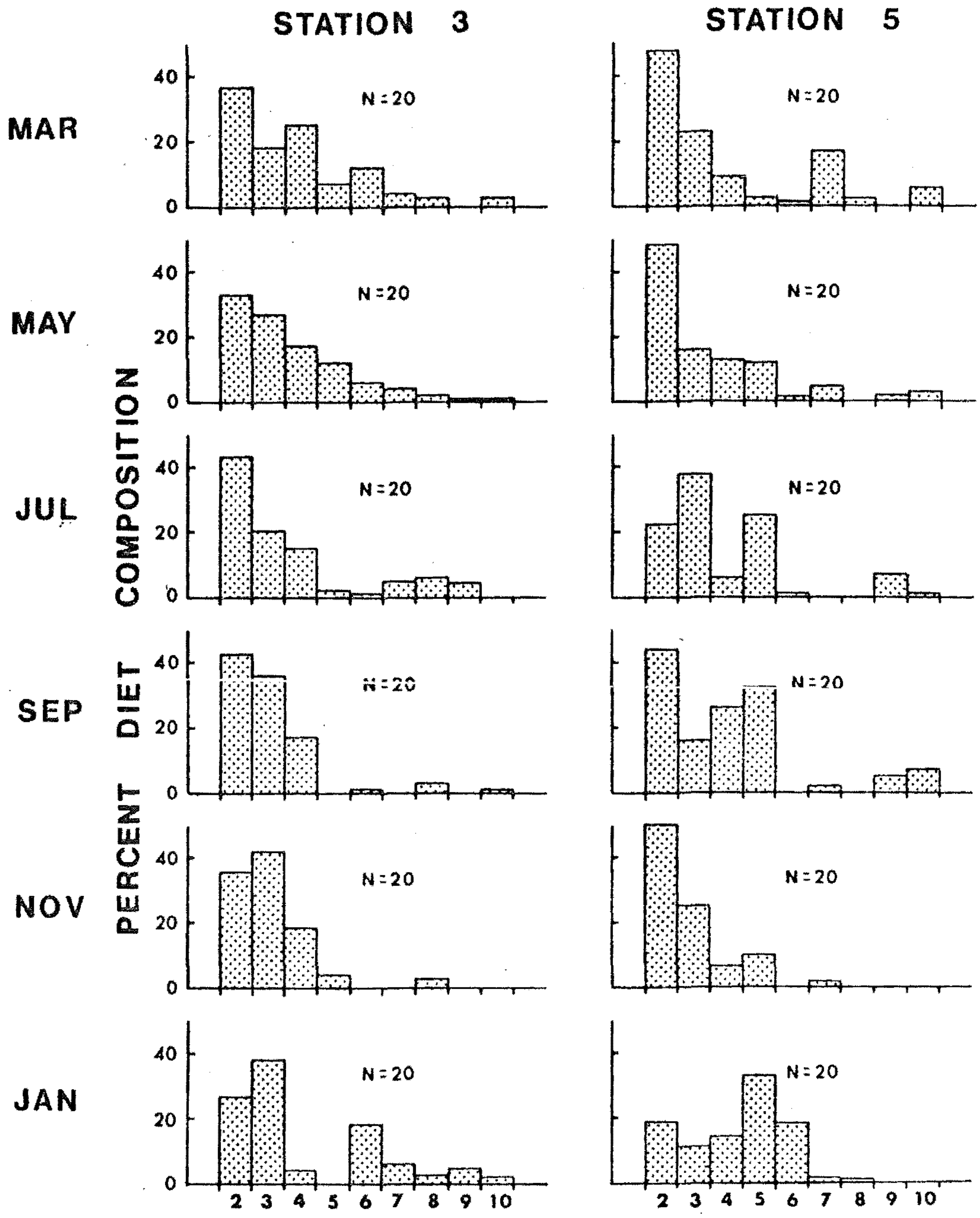


Fig. 14: Seasonal variation in feeding for 0+ sand flounder between March 1970 and January 1971 (see Table 8 for key).

Table 9: Monthly percentages of food and empty volume compositions (N = 40/month).

Month	Percent food volume	Percent empty volume
March	67.0	33.0
May	45.6	54.4
July	39.4	60.6
September	39.5	60.5
November	48.1	51.9
January	76.8	23.2

breviceps Stokell that a 20-fold increase in the rate of digestion occurred in summer and this resulted in less food being found in the stomach in summer. In the present study, by contrast, gut fullness was maximal in summer when temperatures are high and therefore probably the rate of digestion could be expected to be high. Therefore the data presented in Table 9 probably gives a true reflection of feeding activity of 0+ sand flounder, with maximum feeding in summer and a minimum in winter.

Variations in Feeding with Length of Fish

Variations in percent diet composition of different size groups of 0+ sand flounder are shown in Fig. 15. For analysis the fish were grouped into 2 cm length classes.

The most obvious change in diet as 0+ fish increased in size was that they ingested more animal food (an increase from 30-40 to 70-80%) and less sand (a decrease from 50-60 to 20-30%). G statistics showed that these differences in proportions of sand ingested between size classes were significant (G values were 19.53 for Station 3 and 39.24 for Station 5 compared with

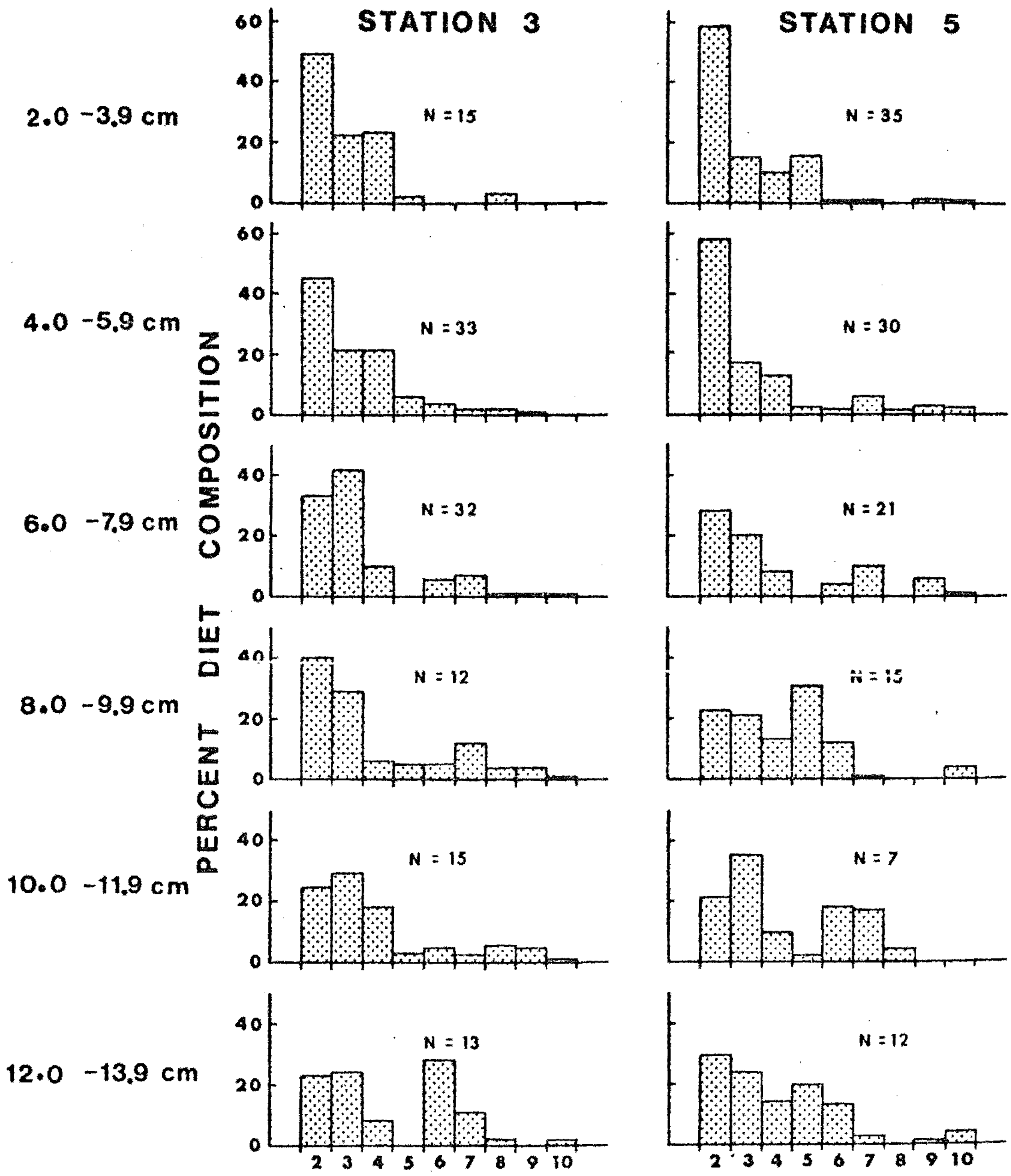


Fig. 15: Variation in feeding with length of 0+ sand flounder (see Table 8 for key).

the critical $\chi^2_{0.01}$ value of 15.09). Sand may dominate the gut contents because it is accidentally ingested while feeding on other food, and young small fish inexperienced in feeding may take in more sand when feeding on polychaetes and other animals than larger experienced fish.

Polychaetes averaged 20-30% in diet volume but showed no significant differences between size groups.

Amphipods formed a substantial part of the diet only at Station 5 where there was a significant G value of 51.54 compared with the critical $\chi^2_{0.01}$ value of 15.09 for differences between size groups. However, no trend of consumption was apparent as the size groups 2.0-3.9, 8.0-9.9 and 12.0-13.9 contained 20% amphipods, whereas the other groups had eaten very little of this food. Mundy (1968) found a definite pattern of consumption in offshore sand flounders; amphipods rating high at 30% in 0+ fish, but falling to 5% in 4+ fish. Webb (1966) found a similar pattern of feeding with a summer abundance of amphipods in older age classes. No summer abundance was noted in the present study.

Decapods became more common in the diets of larger 0+ fish (G values for significant differences between size groups were 17.77 for Station 3 and 32.22 for Station 5, compared with the critical $\chi^2_{0.01}$ value of 15.09). Mundy found a similar pattern, decapods representing an increasing volume from 5% in 0+ fish to 65% in 4+ fish. A increase in carapace size of ingested decapods corresponding to an increase in length of sand flounder was noted by Webb.

The feeding of 0+ sand flounder is influenced by the size of the potential food items, and although polychaetes and amphipods formed the bulk of the identifiable food of 0+ fish in the Estuary, there was a change in the type of food eaten as size increased. In particular, decapods became more common and the size of polychaetes and amphipods increased in the diet of larger fish. The pattern of change is similar in other flatfish; young plaice, for example, feed chiefly on polychaetes and amphipods, with increase in size molluscs take first place (Edwards and Steele, 1968). It has been recently shown that during the life cycle of some flatfishes that changes in relative lengths of certain parts of the alimentary tract can be correlated with changes in food preferences (Brader and De Groot, 1973).

A comparison of Webb (1966) and the present study for food intake of sand flounder inhabiting the Estuary is shown in Table 10. The values shown for the present study were

Table 10: Comparison of annual food intake for sand flounder

Food category	Total food intake/year (percent)	
	Webb (1966)	Kilner (1974)
Sand	32.4	30.5
Digested matter	18.3	20.5
Polychaeta	19.3	20.3
Mollusca	6.5	3.3
Siphons	-	4.5
Amphipoda	10.7	9.7
Decapoda	8.3	5.3
Coelenterata	1.4	0.1
Nemertea	-	1.9
Megalopa larvae	0.3	-
Algae	2.9	3.6

calculated using the method outlined by Webb. Results of the two studies were very similar, the main differences being the higher values for molluscs and decapods found by Webb reflecting the different age groups studied by the two investigations.

Variations in Feeding with Station

Variations in feeding both seasonally and in relation to size at Stations 3 and 5 have been shown in Figs. 14 and 15.

Polychaetes were eaten more commonly at Station 3 on a seasonal basis (G values for significant differences between stations were 8.91, 10.94 and 8.62 for September, November and January respectively, compared with the critical $\chi^2_{0.01}$ value of 6.64). However there were no significant differences between stations in the amount of polychaetes eaten by the different size groups of fish.

Amphipods were eaten to a significantly greater extent at Station 5 both seasonally (G values were 23.17, 45.75 and 45.75 for July, September and January respectively, compared with the critical $\chi^2_{0.01}$ value of 6.64) and by different size groups (G values were 8.74, 14.56, 20.90 and 26.34 between stations for four of the six size groups, compared with the critical $\chi^2_{0.01}$ value of 6.64).

Overall, the diet tended to be more varied at Station 3 in the middle reaches of the Estuary than at Station 5 which was further towards the head. At Station 3 the major food items were polychaetes and sand with less important items being amphipods, siphons, decapods, bivalves, gastropods, anemones, algae and digested matter. By comparison at Station 5 polychaetes, amphipods and sand were the major food items with siphons, decapods and digested matter being less important. The increased use of amphipods can be related to their greater abundance there as found by Voller (1973). The less varied diet found at Station 5 may reflect the lower animal species diversity found in this more polluted area.

6.4 Conclusion

Age 0+ sand flounder fed predominantly on invertebrate bottom fauna, but sand was a major item in the gut contents and whether this was accidentally ingested or the detritus and micro-organisms contained in the sand ~~was~~ were being used as a direct source of energy was not established.

The diet of 0+ sand flounder was observed to shift from smaller to larger food items with increasing age, and also varied between stations and seasonally to some extent. Food specialization exhibited by different age groups at the same time of the year could lessen competition between age groups.

A seasonal cycle of feeding, as indicated by gut fullness, appeared to be correlated with temperature, however the potential gut volume was never fully utilized; the highest percent occurrence of food was 76.8% by volume (January) and the lowest 39.4% (July). The summer abundance of many young sand flounder with their high energy requirements may exaggerate the summer peak.

The effect of the proposed barrier and channel dredging on the feeding habits of 0+ sand flounder will be discussed in Chapter 8.

7. DISTRIBUTION AND MOVEMENTS

7.1 General Introduction

The distribution and movements of 0+ sand flounder Rhombosolea plebeia and the underlying factors causing them are relatively unknown. Similarly, there are few studies of juvenile flatfish of other species (Pearcy, 1962).

The survival, distribution and movements of 0+ sand flounder are presumably the result of both biotic and abiotic factors. Important abiotic factors may include fluctuations in salinity, temperature, current velocity and tidal rise and fall, and an important biotic factor will be the distribution of food organisms. In this study, emphasis has been placed on examining the effect of salinity upon 0+ fish, since closure of the proposed barrier will have a considerable effect on the salinity regime of the Estuary.

7.2 Distribution

Introduction

Sand flounder are not randomly distributed in the Estuary (Webb, 1966), and Webb who studied the distribution principally of the older age classes, noted that many young fish occurred in the middle reaches and older age classes nearer the Estuary mouth. The present study was undertaken to enlarge the knowledge of the distribution of the juvenile fish and to consider some of the factors underlying this distribution.

Method

An intensive sampling programme was undertaken in October 1970. By concentrating fishing to a short period the effects of migration and mortality on the results were minimized. Samples were obtained from Stations 1-6 (Fig. 1) which were spaced at regular intervals between the mouth and the head of the Estuary. Standard trawls made with a beam trawl (width 1.5 m) between buoys a known distance apart (usually 150 or 200 m), were carried out at a speed just below 35 m/min. This speed was that recommended by Riley and Corlett (1965) for 0+ plaice *Pleuronectes platessa* L. and in the present study was also found to be most suitable for keeping the beam trawl on the bottom and for obtaining maximum catches of 0+ fish of all sizes. Numbers of fish captured in each trawl were converted to numbers /100 m^2.

Collections were made at random locations in the vicinity of each station, to reduce the possibility of depleting the numbers of juveniles in localized areas. No effects of fishing effort were observed after repeated sampling.

Results and Discussion

The maximum abundance of 0+ sand flounder was found in the middle reaches of the Estuary, numbers tapering off towards both the head and the mouth (Table 11).

Comparatively few 0+ fish were captured at the mouth, where swift currents may sweep both larvae and small fish away. Salinity had a strong influence in restricting the distribution of fish upstream. The maximum rate of salinity change in the bottom water was similar at Stations 3-6, however the length of time over which fish were exposed to salinities $< 1.0^{o}/oo$

Table 11: Distribution of 0+ sand flounder

Station	0+ Sand Flounder			Current Velocity		Sediments*		Salinity (bottom)	
	Mean No./100 m^2	S.D.	No. of trawls	Max. velocity m/sec Flood	Ebb	% silt-clay	% organic matter	Hrs of tidal cycle $< 1^o/oo$	Max. Rate of salinity change/hr ($^o/oo$)
1	0.4	0.53	8	1.5	1.8	<10	<1.0	0	3.5
2	6.3	5.42	14			<20	1.0-2.0	0	6.5
3	10.5	8.61	28	1.2	1.3	<20	1.0-2.0	0	15
4	5.3	4.71	9			20-40	1.0-2.0	1.0	17
5	3.7	3.03	8			20-90	2.0-7.0	3.25	19
6	0	0	5	0.9	0.6	40-90	3.0-7.0	6.5	16

* from Knox and Kilner, 1973.

steadily increases from Stations 3-6. Station 6 has 6.5 hours of essentially freshwater each tidal cycle and absence of fish here was probably not because they were unable to exist at the low salinities found (most could survive the length of exposure to $< 1.0^{o}/oo$, see Chapter 7.3), but because they prefer higher salinities and move away from this area. Maximum abundance occurred at Station 3 where salinity does not drop below $5^{o}/oo$ (Fig. 4). Food supply may also have an effect on the fish distribution, and it was noted (see Chapter 6) that a greater variety of food was eaten at Station 3 than at Station 5.

One important factor affecting abundance data that must be considered here is the problem of escapement of fish from the net. Stations 1-3 have similar sediments and while escapement may be high (see Chapter 2.2) it is probably of the same order of magnitude at these stations. Stations 4-6 have sediments that contain a much higher percentage of silt-clay and organic matter which results in a 'soft' sediment. As young flounder readily bury themselves, two tickler chains were added to the net when sampling at these stations in an attempt to disturb the fish out of the sediment. Nevertheless it is probable that escapement from the net was higher in these soft sediments. The results for Stations 4 and 5 therefore are probably underestimates of relative abundance. Despite these limitations, it is clear that the highest numbers of newly settled fish and probably the most juveniles occur at Station 3.

The distribution of 0+ fish over the 12 month sampling period of the present study confirmed the pattern of distribution shown in Table 11. October was the peak month for settlement of young fish and in later months the size of fish captured tended to be larger.

These results cannot be used to estimate the actual abundance of 0+ sand flounder on a annual basis. The seasonal bloom of algae in summer for instance, radically altered the catch per unit effort and no satisfactory method could be devised to compensate for such variations.

7.3 Salinity Tolerance Experiments

Introduction

Salinity was found to have a marked influence on the upstream distribution of 0+ sand flounder and closure of the proposed barrier will have a marked effect on the salinity regime of the Estuary. In the light of these factors it was decided to investigate the salinity tolerance of 0+ sand flounder, as the results might enhance understanding of the field distribution and effect of the barrier on the fish.

Method

Age 0+ sand flounder were collected from the Estuary and used in salinity tolerance experiments carried out in September and October 1970.

A series of dilutions of sea water (freshwater, 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0 and 34.2^o/oo) were maintained in covered aquarium tanks, 60 x 38 x 37 cm, volume 50 l. Salinity was determined by the method of Schales and Schales (1941). Low salinities were obtained by diluting sea water with artesian tap water. All salinities were checked daily and maintained at the required salinity $\pm$ 0.1^o/oo.

Experiments took place at 15.1 $\pm$ 0.8^{o}C in a temperature controlled room. Temperatures were higher than desired but it was the only temperature available and it did not exceed the mean summer water temperature in the Estuary (Fig. 2A). Natural light dark conditions were used and the water was kept oxygenated.

Fish were fed daily on chopped mussels, Mytilus edulus aotenus L. and Perna canaliculus (Martyn), and any food not eaten after two hours was removed. The water was changed every second day to prevent bacterial growth in the water as an attempt to use penicillin to control bacteria proved unsuccessful.

Experiments were of two types. (a) With no acclimation, fish were placed directly into each salinity from sea water and (b) with acclimation, where sea water was progressively diluted until it reached $0.5^{o}/oo$ after 48 hours in order to test if fish survived longer when gradually exposed to this low salinity. Control experiments were carried out under the same conditions of water temperature, aeration and feeding.

Ten or 12 fish were tested at each salinity, experiments were repeated and results combined. To test whether size of fish had an effect on salinity tolerance half of the fish at each salinity were < 7 cm total length and the other half ≥ 7 cm.

Experimental tanks were checked as frequently as possible, dead fish were removed and measured and their survival times recorded.

Results and Discussion

Age 0+ sand flounder survived the two month experimental period in salinities above $4.0^{o}/oo$ without any acclimation. There was reduced survival with increasingly lower salinities below $4.0^{o}/oo$ (Fig. 16). Median survival times (LD_{50}) ranged from 457 hours at $4.0^{o}/oo$ to 43 hours in freshwater. LD_{50} for $0.5^{o}/oo$ in the acclimation experiment was 76 hours, ie. fish

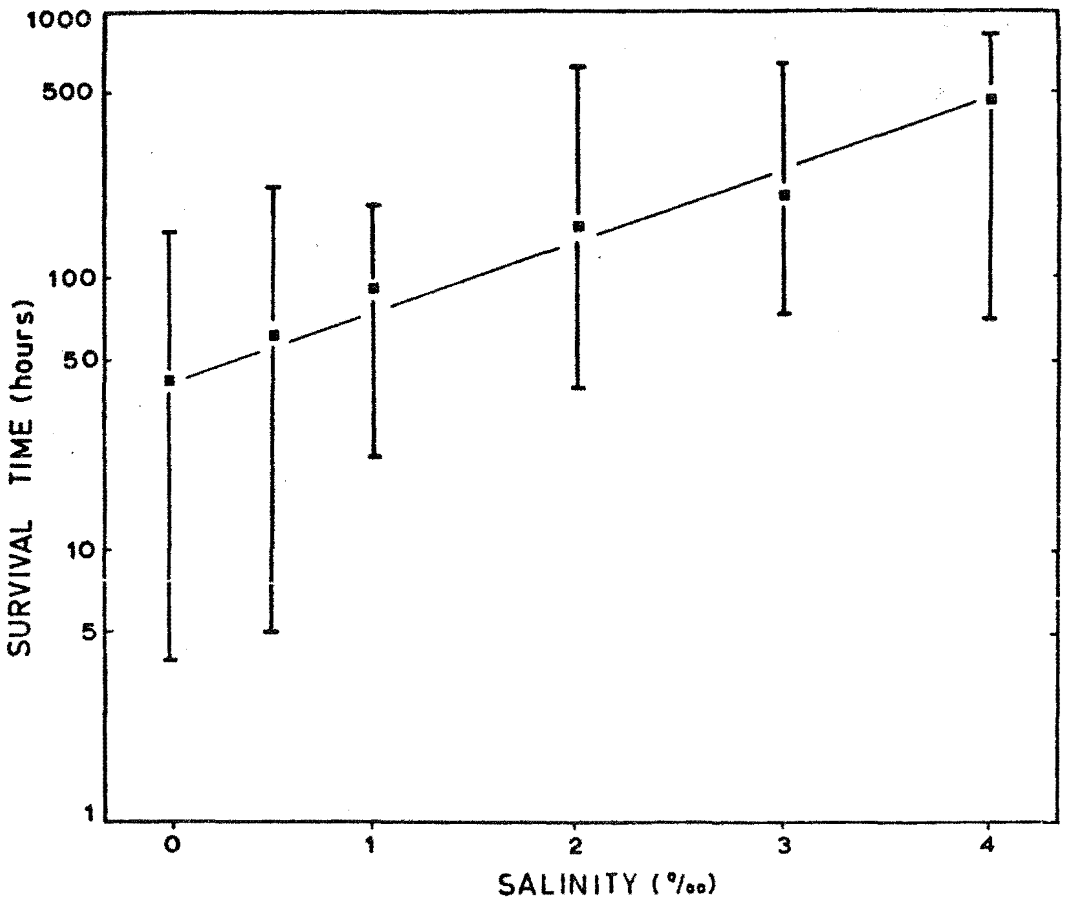


Fig. 16: Survival of 0+ sand flounder in different salinities. For each salinity: median survival time represented by the solid square; range of survival by the vertical bars.

survived 12 hours longer when gradually exposed to this salinity.

LD_{50} was used as a measure of salinity tolerance rather than mean survival time since a few highly resistant fish will tend to bias the mean. Both acclimation and non-acclimation experiments show large variations (ranges) in tolerance around LD_{50}. These large ranges indicate individual differences in tolerance which may partially be the result of two physiological races being present, as Mundy (1968) has shown that Estuary fish are derived from two stocks, one spawning on the Flounder Patch and the other on the Winter Ground. The presence of some yellow bellied flounder (see Chapter 2.2) which may have different physiological tolerances, could also have affected the results.

The survival of 0+ sand flounder in low salinities could be expected since it is a euryhaline fish and Pearcy (1962) has found similar minimum salinity tolerances for small individuals of the estuarine winter flounder Pseudopleuronectes americanus (Walbaum).

Survival times of the two size groups of fish (<7 cm, ≥ 7 cm total length) were tested using Wilcoxon's two-sample test (Sokal and Rohlf, 1969, pp. 391-395) for each salinity (Table 12). A non-parametric test was chosen since the null hypothesis does not specify the shape of the distribution, whereas parametric tests assume normality. Smaller fish were significantly more susceptible to freshwater and salinities of 0.5 and 1.0^{o}/oo at the 0.01 level of U. Significant differences were not found at salinities of 2.0, 3.0 and 4.0^{o}/oo although smaller fish still had lower ΣR values (sum of ranks) supporting this trend towards shorter survival of small fish. A number of studies of other marine fish have found a marked increase in salinity tolerance with size (Huntsman and Hoar, 1939; Parry,

Table 12: Survival of two size groups ($G_1 < 7$ cm, $G_2 \geq 7$ cm) of 0+ sand flounder in different salinities
(L = total length in cm, S = survival time in hours, R = rank in order of survival time,
N = number of fish and U_s = Mann-Whitney statistic)

Freshwater

	G_1 L	G_1 S	G_1 R	G_2 L	G_2 S	G_2 R
	4.7	4	2	10.0	20	6
	5.0	4	2	9.5	28	9.5
	5.2	4	2	8.5	45	13.5
	3.5	15	4	12.1	57	16
	5.4	18	5	8.0	64	17
	3.8	21	7	10.3	76	18
	6.4	25	8	7.3	83	19
	6.9	28	9.5	8.2	108	20
	3.9	43	11.5	8.1	119	21
	6.6	43	11.5	12.9	135	22
	5.3	45	13.5	7.5	150	23.5
	4.8	46	15	8.1	150	23.5
N		12			12	
ΣR		91			209	
U_s			131*			
$U_{0.01}$			117			

0.5 ‰

	G_1 L	G_1 S	G_1 R	G_2 L	G_2 S	G_2 R
	2.3	5	1	7.9	117	15
	4.4	13	2	7.4	122	16
	2.5	23	4	8.2	126	17
	2.6	23	4	7.3	141	18
	4.1	23	4	10.9	142	19
	2.8	37	6	8.7	168	21
	3.1	46	7.5	7.0	192	22
	4.2	46	7.5	8.9	205	23
	2.3	51	9.5	11.8	228	24
	3.6	51	9.5			
	3.3	55	11			
	3.5	64	12			
	2.8	77	13			
	2.8	103	14			
	6.0	145	20			
N		15			9	
ΣR		125			175	
U_s			130*			
$U_{0.01}$			111			

1.0 ‰

	G_1 L	G_1 S	G_1 R	G_2 L	G_2 S	G_2 R
	3.1	22	1	10.2	57	5.5
	3.8	34	2	10.8	67	7
	5.1	38	3	9.0	92	11
	3.5	50	4	12.5	97	13
	5.8	57	5.5	8.5	100	14
	6.9	81	8	8.3	121	15
	6.1	85	9	7.8	165	17
	6.1	90	10	7.4	176	18
	5.4	95	12	7.3	188	19
	5.9	144	16	10.4	190	20
N		10			10	
ΣR		70.5			139.5	
U_s			84.5*			
$U_{0.01}$			84			

2.0 ‰

	G_1 L	G_1 S	G_1 R	G_2 L	G_2 S	G_2 R
	3.9	40	1	8.5	103	3
	2.8	76	2	10.5	117	4
	3.8	122	5	8.2	128	7
	3.7	123	6	8.0	133	9.5
	6.5	133	9.5	8.2	133	9.5
	5.8	196	13	10.4	133	9.5
	3.3	204	14	7.8	158	12
	5.4	216	15	10.0	231	16.5
	5.8	231	16.5	7.8	383	18
	4.7	427	19	7.8	533	20
	5.9	545	21	10.1	561	22
	5.7	589	23	8.7	600	24
N		12			12	
ΣR		145			155	
U_s			77			
$U_{0.01}$			117			

3.0 ‰

	G_1 L	G_1 S	G_1 R	G_2 L	G_2 S	G_2 R
	5.4	74	1	9.4	90	2
	6.8	109	4	9.1	95	3
	5.8	144	6	12.0	144	6
	6.0	144	6	9.0	190	9
	6.3	166	8	8.2	200	10
	5.9	297	12	8.8	208	11
	3.1	360	13	7.3	403	14
	4.5	423	15	7.9	510	16
	3.5	588	18	7.0	551	17
	3.8	598	19	9.6	623	20
N		10			10	
ΣR		102			108	
U_s			53			
$U_{0.01}$			84			

4.0 ‰

	G_1 L	G_1 S	G_1 R	G_2 L	G_2 S	G_2 R
	6.7	102	2.5	7.8	71	1
	4.6	116	4	9.0	102	2.5
	4.4	121	5	8.0	233	6
	6.6	241	7	8.6	261	8
	6.7	295	9	8.8	304	10
	3.7	361	11	7.5	457	12
	4.0	479	14	9.0	476	13
	6.7	495	16	7.9	483	15
	5.0	502	17	9.8	605	19
	3.1	532	18	9.4	638	20
	3.0	647	21	7.9	662	22
	6.8	694	23	10.8	704	24
N		12			12	
ΣR		147.5			152.5	
U_s			74.5			
$U_{0.01}$			117			

* Mean survival time significantly lower for G_1 than G_2 at the 1% level of U

1958, 1960; Holliday and Jones, 1967; Otto, 1971), an increase in salinity tolerance with size probably resulting from the development of more efficient salt regulating mechanisms. In plaice Pleuronectes platessa it has been shown with progression from larvae to juvenile to adult development of more efficient salt regulating mechanisms occurs both in the respiratory filament cells in the gills and in the tubules and glomeruli of the kidneys (Parry, Holliday and Blaxter, 1959; Parry, 1966; Holliday and Jones, 1967; Holliday, 1971). Such development is probable in sand flounder as the early life history begins in the sea but often 0+ fish develop in estuaries where better salt control would be required.

Raj (1973) has studied control of salt balance in adult sand flounder and found that they follow the general pattern of salt balance control exhibited by most estuarine fish. Osmotic concentration of the blood and tissues is lower than that of the surrounding sea water and results in a continual loss of water from the body by osmosis and a salt gain by diffusion. To maintain salt balance, sand flounder swallow seawater, and in the intestine 75% of the water, 90% of the monovalent ions (Na^+, Cl^-, K^+), 21-25% of the divalent ions (Mg^{++}, SO_4^{--}) and 61% of the calcium ions are absorbed from the sea water. In the kidneys the divalent ions are secreted across the tubules and excreted in the urine whereas most of the water and monovalent ions are reabsorbed across the tubules. Most of the monovalent ions are secreted by the gills and calcium ions are probably lost from the fins. Raj found that adult sand flounder osmoregulated satisfactorily in water down to about 38% sea water (12.6-13.6^o/oo salinity) which is relatively isosmotic to their blood concentration.

Adaptation to reduced salinity was most obvious near the isosmotic point where a decrease in drinking rate was observed compared with that in sea water. Below 12.6-13.6^{o}/oo sand flounder gills were unable to reduce loss of monovalent ions and death eventually occurs. Sand flounder therefore are partially euryhaline (Raj, 1973).

In the present investigation 0+ sand flounder survived salinities of 5 and 10^{o}/oo for all of the 45 days until the experiment was terminated. No explanation is apparent for the different results obtained by Raj and myself. A possible explanation could be that 0+ fish have a lower isosmotic point than adults but this does not account for smaller fish being more susceptible than larger 0+ fish. A factor that may have some influence on these results is the time of the year in which the experiments were carried out and Raj (pers.comm.) has reported that there is some evidence that adult flounder are better able to adapt to dilute sea water at certain times of the year than at others. Development and mechanisms of control of salt balance in 0+ sand flounder requires further study.

The design of my experiments created artificial conditions for 0+ sand flounder as they were confined in glass tanks without sediment, and this may have affected the results. It is known that some organisms can tolerate a lower salinity in laboratory experiments than in their normal environment (Riley, 1967). In the Estuary flounder bury into the surface of the sediment and they may benefit from the salinity of the interstitial water and not be subjected to that of the overlying water. Interstitial salinities in the Estuary are similar to mean salinity of the overlying water and tend to remain relatively constant not being altered by fluctuations in salinity of the overlying water to any marked extent (Voller, 1973).

Experimental work beyond the scope of the present study needs to be carried out to show in particular the interrelationship between temperature and salinity on 0+ sand flounder. In the present study experimental temperatures were about 15°C while Estuary water temperatures ranged between 10-16°C during the same months of the year. It is unlikely that the experimental temperatures assisted survival of 0+ fish as it is well known that other species of flounder survive low salinities better at colder temperatures (von Westerhagen, 1970; Holliday, 1971).

7.4 Distribution of 0+ Sand Flounder at Station 3

Introduction

Station 3 had the greatest abundance of 0+ sand flounder (Table 11). From casual observations also it appeared that this station had the greatest abundance of small recently settled fish in the pools left exposed on the mudflats at low tide. It was considered that these observations warranted a more detailed examination of the fish distribution at this station, both of how different sizes of fish were distributed, since differences in salinity tolerance with increasing size have been shown to exist, and of some of the other factors that may bring about these distributions.

Method

The beam trawl was used for capturing 0+ fish at Station 3 during November, 1970. Three locations at high and low tide were sampled; pools on mudflats, streams draining mudflats, and main river channel. At high water the trawl was towed behind the boat and at low water it was manually hauled through the pools and streams. Total lengths of fish were measured and at each fishing locality, bottom water salinity was taken.

Results and Discussion

Length frequency distributions of 0+ fish at all these locations are presented in Fig. 17. Statistical parameters derived from these length frequency distributions and salinities measured at these locations are shown in Table 13.

Table 13: Statistical parameters derived from length frequency distributions of 0+ sand flounder in relation to salinities measured at different localities at Station 3.

Locality	Tidal Level	Length (cm)				Salinity ($^o/oo$)		
		N	$\bar{x}$	S.E.	S.D.	N	$\bar{x}$	Range
Mudflat	High water	340	3.96	0.108	1.992	9	31.0	28.6-32.7
	Low water	126	2.16	0.070	0.789	12	26.0	20.0-32.5
Stream	High water	199	8.14	0.200	2.820	8	30.2	27.6-32.8
	Low water	627	5.20	0.040	0.994	13	27.3	23.8-32.4
Channel	High water	92	9.11	0.293	2.815	19	33.3	31.3-34.1
	Low water	183	9.93	0.190	2.573	9	7.3	5.3-10.8

At low water, length frequency distributions of fish show a distinct pattern with small individuals predominating in pools, intermediate sizes in the streams and generally only large fish in the channel. At high water it was found that large individuals had migrated from the channel into the streams and some intermediate sizes had moved from the streams onto the mudflats. The

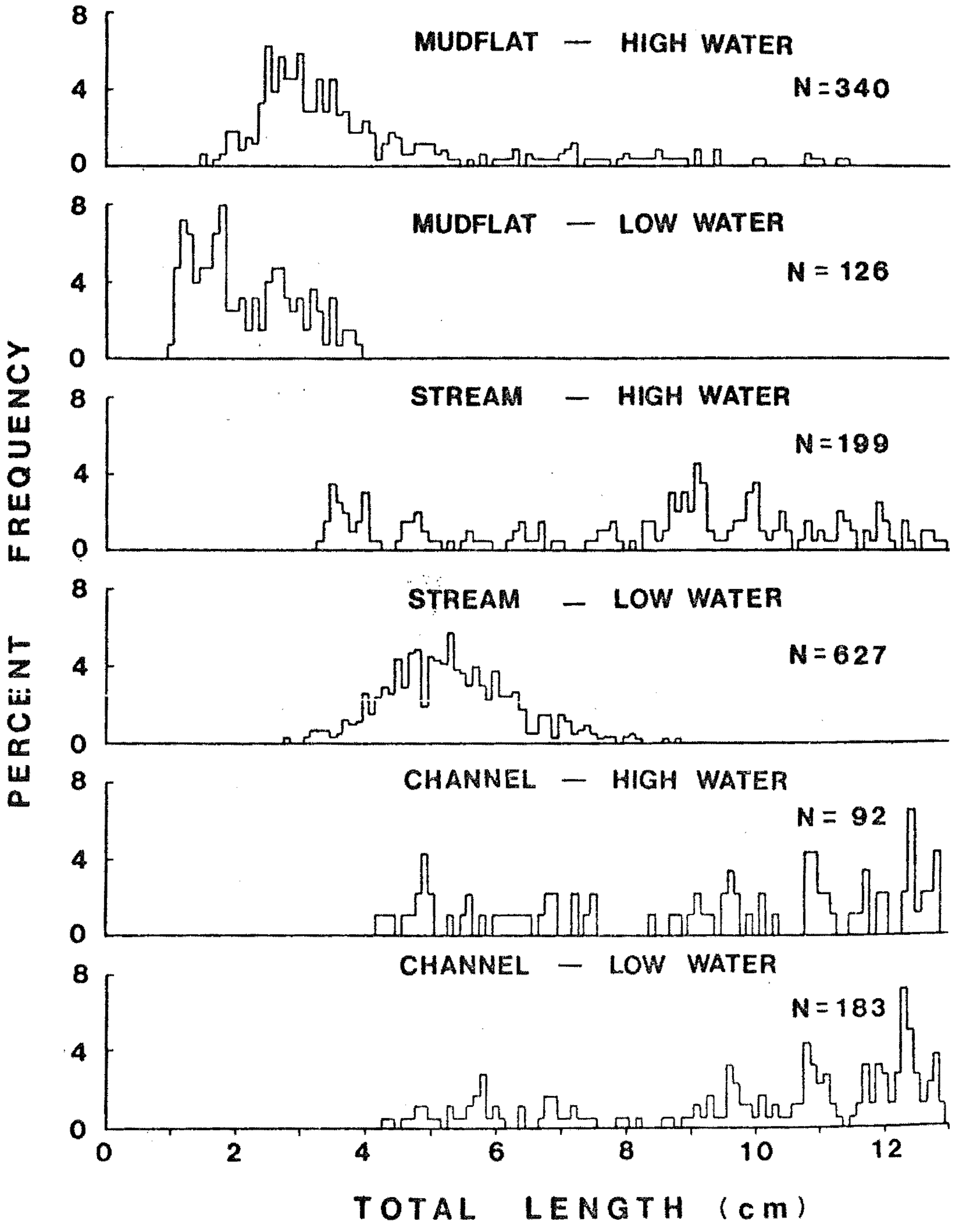


Fig. 17: Length frequency distributions of 0+ sand flounder captured at high and low water in three localities at Station 3 in November 1970.

significant point of these distributions is that low tide salinities are much lower in the channel than in nearby streams and pools, and it has been shown (see Chapter 7.3) that smaller fish are significantly more susceptible to low salinities. This is evident in the distribution of 0+ fish, as the smaller juveniles tended to remain in the streams and pools at low tide where the water remains saline (23.8-32.5^{o}/oo) once the tide has receded. Therefore young fish are most abundant in the mudflat streams and pools in the middle reaches of the Estuary (Fig. 18). Only larger more tolerant fish are found in the channels where the saline water is being continually diluted by freshwater as the tide recedes.

Other factors besides salinity influence these distributions. Mudflat streams and pools at Station 3 have lower velocities (see Chapter 2.1) and longer periods of slack water than the channel. Therefore young fish may select these streams and pools as less energy expenditure is necessary to prevent them being carried away. On the other hand, temperatures in these pools can become very high for short periods of time (I have recorded temperatures of 29^{o}C) in summer, when large numbers of young fish are present. Young sand flounder are tolerant of these high temperatures. High temperature tolerance may be linked with high salinity tolerance, as Waede (1954) has demonstrated greater resistance to high temperatures of the estuarine flounder <u>Pleuronectes flesus</u> L. when higher salinities were present. As high temperature reduces the oxygen saturation level of the water, this may indicate that young fish are also tolerant of low oxygen levels in high salinities. Alternatively it is possible that many susceptible fish die under conditions of high temperature-low oxygen without being noticed.

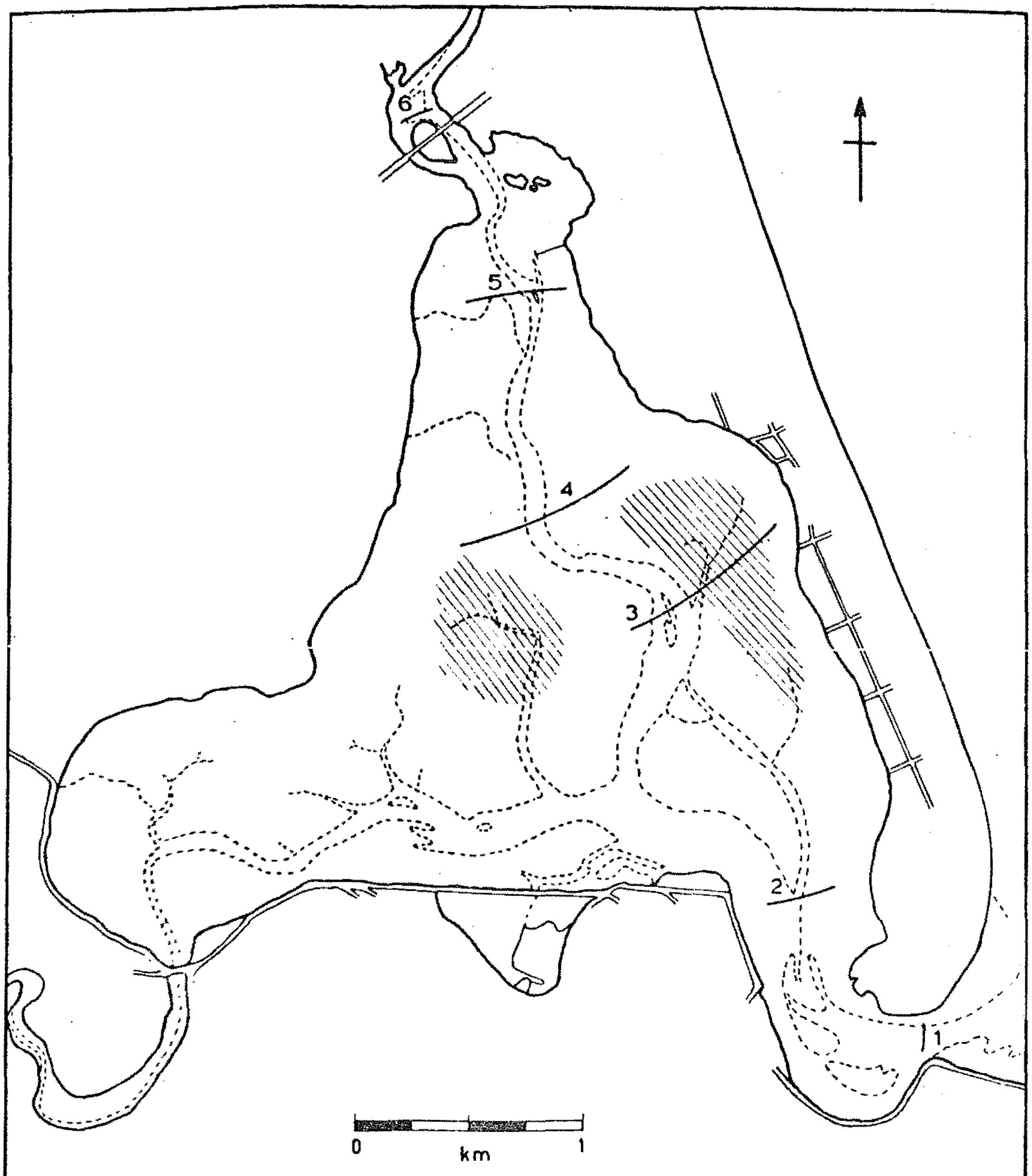


Fig. 18: Principal areas of abundance (hatched) of young 0+ sand flounder in mudflat pools and streams. Trawl Stations 1-6 are also shown.

7.5 Movements and Dispersion

Introduction

Age 0+ sand flounder inhabit most estuaries, bays and harbours around Banks Peninsula. These are shallow water areas and are known to act as nursery grounds for these fish. In many species of flatfish the young stages enter the intertidal zone to feed as the tide floods (Gibson, 1973). Little detailed information is available on intertidal movements for 0+ sand flounder. Gibson (1973) has recently studied the nature and extent of these movements for young stages of plaice *Pleuronectes platessa* L. and Tyler (1971) has studied these movements for young winter flounder *Pseudopleuronectes americanus* (Walbaum) by means of an underwater television camera. Little is known about the movements and dispersion of 0+ sand flounder within the Estuary and whether they emigrate from the Estuary into adjacent areas.

The present investigation studied the intertidal movements of 0+ sand flounder in one area of the Estuary by sampling the intertidal region at high water, and a preliminary investigation was made of dispersion using a fish marking programme.

Method

(1) Intertidal Movements - This study was carried out at Station 3 on 14-18 November, 1970. The short sampling period minimized the chance of variation in numbers captured due to mortality or emigration.

The tidal range was about 1.8 m and the distance between high and low water mark was about 390 metres at the time of sampling.

For sampling purposes a number of stations were established, one in the low water channel, one at low water mark, and others 50 m, 100 m, 200 m, 300 m and 350 m up the shore in the inter-tidal region. Buoys were moored at these stations and a duplicate set at the same levels 150 m further along the shore so that the same distances and levels were sampled on each occasion. Samples were taken parallel to the shore between each pair of buoys in a period one hour either side of high water on five consecutive days.

The 1.5 m beam trawl was pulled by hand in shallow water and by boat in deeper water at a speed just less than 35 m/min. Trials when the net was towed by hand and by boat showed no significant differences in catches. No true estimate of the catching efficiency of the net was made.

(2) Dispersion - The investigation of dispersion was carried out by marking fish using a jet inoculator, as described by Hart and Pitcher (1969).

Fish were marked on the non-pigmented surface, as a mark on this surface probably would not affect predation on the sand flounder as they are a bottom living species. When marking, fish were anaesthetized in a shallow tray containing sea water to which a saturated solution of benzocaine was added. Dosage depended on temperature and was adjusted to give complete anaesthesia in three minutes, as indicated by the total loss of motor coordination. Anaesthetized fish were laid on a wet cloth and the dye was administered with the nozzle of the inoculator held about 5 mm above the marking site. Excess dye was removed by washing in water and the fish inspected to see that a clear mark had been made. Fish larger than 4 cm total length were successfully marked; fish smaller than this were fatally damaged.

The investigation of dispersion was preceded by trials to test for retention of marks and the effect of marking on mortality of the fish. Alcian Blue dye at a concentration of 64 mg/ml (as recommended by Kelly, 1967) and Indian Ink were used to mark two groups of fish; one group had the musculature overlying the vertebral column marked, and the other group had musculature either side of the vertebral column marked. Marked fish were placed with unmarked controls in running sea water tanks and they were examined weekly for three months. A further group of Alcian Blue marked fish were held in two 1.27 cm mesh cages 1x0.6x0.4 m placed in the low water channel at Station 3 and they were usually examined at two weekly intervals. Visibility of marks was classified as follows: good - readily recognizable without close examination, fair - recognizable with close examination, poor - recognizable with difficulty and invisible - not recognizable.

Results are shown in Table 14, no difference was noted between vertebral column and lateral musculature marked fish in loss of marks, therefore the results were combined. No significant difference in mortality was noted between marked and unmarked fish, mortality appeared to be that which occurs naturally under laboratory conditions. Indian Ink marks proved unsatisfactory, 50% were classed as poor after two weeks and 54% were unrecognizable after eight weeks. Alcian Blue marks were satisfactory as all marks were recognizable after three months (Plate 6). In the field experiment marks were recognizable on all fish after two months, however all the fish had died by this time probably from lack of food.

Table 14: Percent of fish in each class of mark visibility and their mortality in a three month period after being marked.

Dye	Time (weeks)	Visibility of Mark %				Mortality %	
		Good	Fair	Poor	Invisible	Marked	Un-marked
Alcian Blue	1	100	-	-	-	-	-
N =20 marked	2	100	-	-	-	-	-
N =20 unmarked	4	100	-	-	-	35	30
	8	91.7	8.3	-	-	40	50
	12	90	10	-	-	50	55
	24	75	25	-	-	60	70
Indian Ink	1	100	-	-	-	-	-
N =14 marked	2	14.3	35.7	50	-	-	-
N =14 unmarked	4	7.1	8.6	50	14.3	-	-
	8	-	18.2	27.3	54.5	21.4	28.6

Therefore for fish larger than 4 cm Alcian Blue marks proved satisfactory, the jet inoculator provided a rapid simple process which gave clear long-lasting marks. This method proved more satisfactory than trials using coloured latex injections (as described by Riley, 1966).

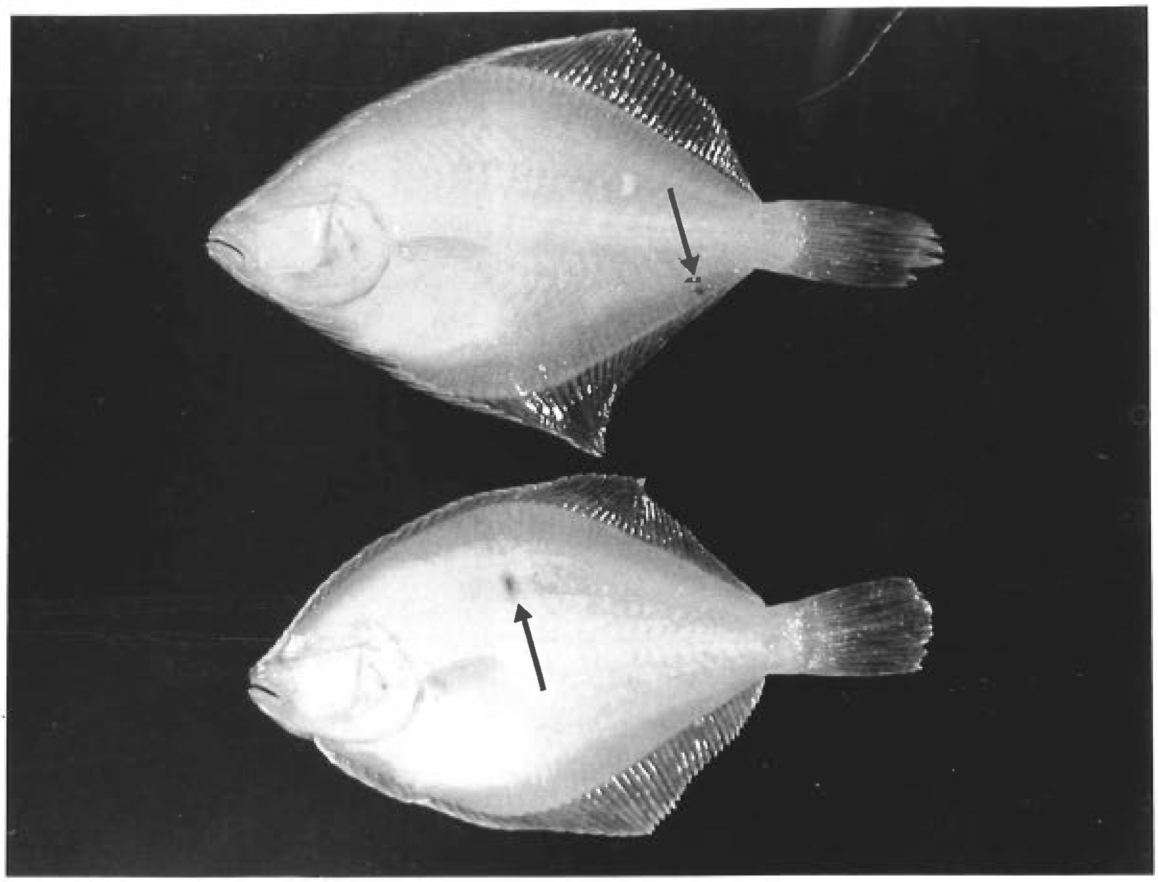
Following the above investigation Alcian Blue marks were used in the field dispersion study. It was intended that this study involve a number of release points throughout the Estuary, each with its own batch mark and large numbers of marked fish. However an untimely illness of the author, followed by a large summer algal bloom terminated the study at an early stage and only fish at Station 3 were marked.

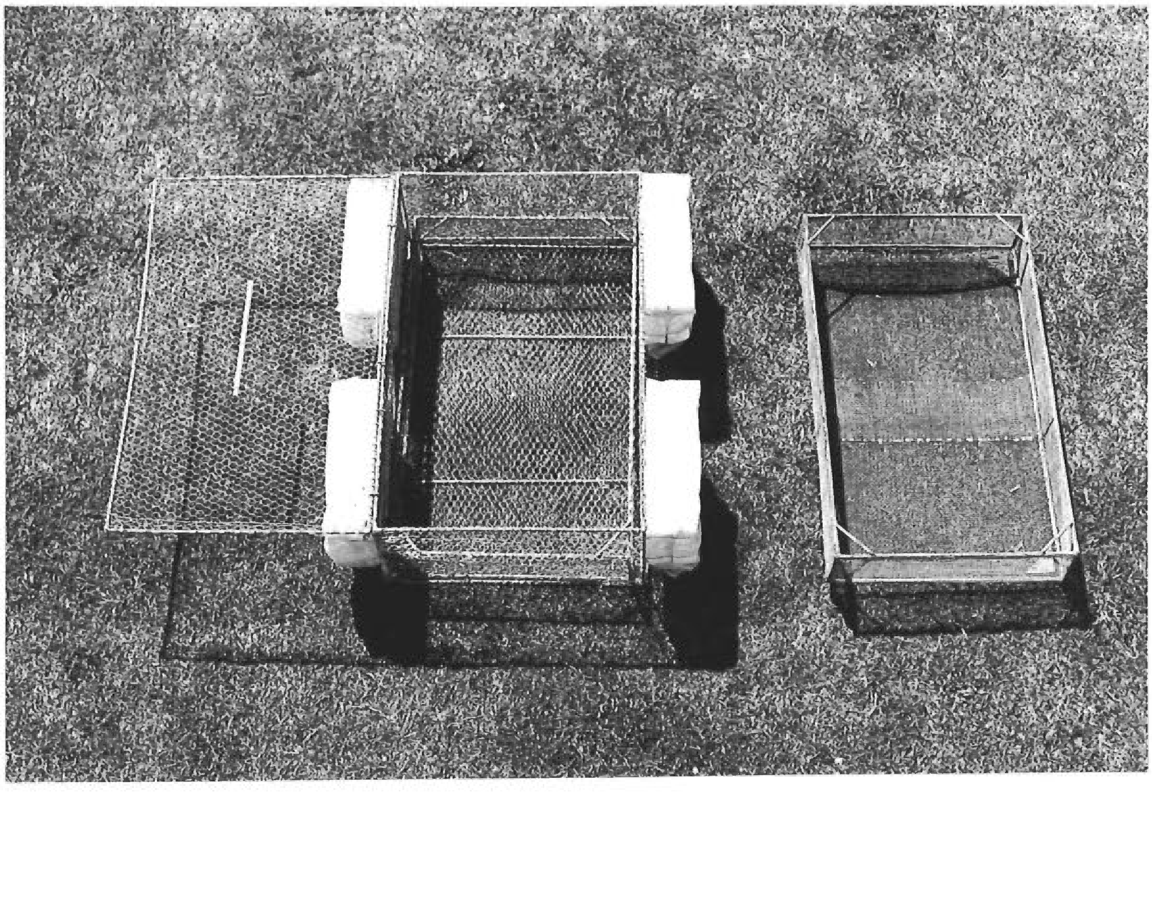
Plate 6: Age 0+ sand flounder (9.5 and 10.4 cm total length) marked with Alcian Blue dye showing visibility of marks (arrowed) after three months.

Photo: H. Best.

Plate 7: Floating cage used for marking fish.

Photo: H. Best.





Fish captured were held in a floating cage 0.8 x 0.5 x 0.3 m (Plate 7) which was found to be necessary to keep fish alive until they could be marked. They were anaesthetized, measured, marked and returned to the floating cage, and only those that were undamaged and exhibiting normal behaviour after 15 minutes were released. The Station 3 batch mark was made over the vertebral column close to the base of the caudal fin. All marked fish were released at a marked buoy. On seven occasions over the succeeding 22 days Station 3 and other parts of the Estuary were sampled. Recaptures were recorded, and any unmarked fish captured at Station 3 were marked and released.

Results and Discussion

(1) Intertidal Movements - Numbers of fish captured in trawls parallel to the shore are shown in Fig. 19. It is evident that the fish move onshore with the flood tide because they are found in the intertidal region at high water. Most fish were found to have moved 100 m from the channel onto the mudflat at high water, some had migrated 300 m but none were found at 350 m. The shallowness of the water in the higher intertidal regions may terminate these migrations. Some of the fish captured may not have migrated from the channel as they could have been living in pools on the mudflat. However, it was shown in Chapter 4.3 that these fish are extremely small and usually escape from the 1.27 cm mesh used.

Tyler (1971) using underwater television observed that winter flounder Pseudopleuronectes americanus surge into the intertidal region on the rising tide, the peak movement into this region occurring 2-2.5 hours after low water. A peak movement offshore occurs 2-0.5 hours before the next low water, and the

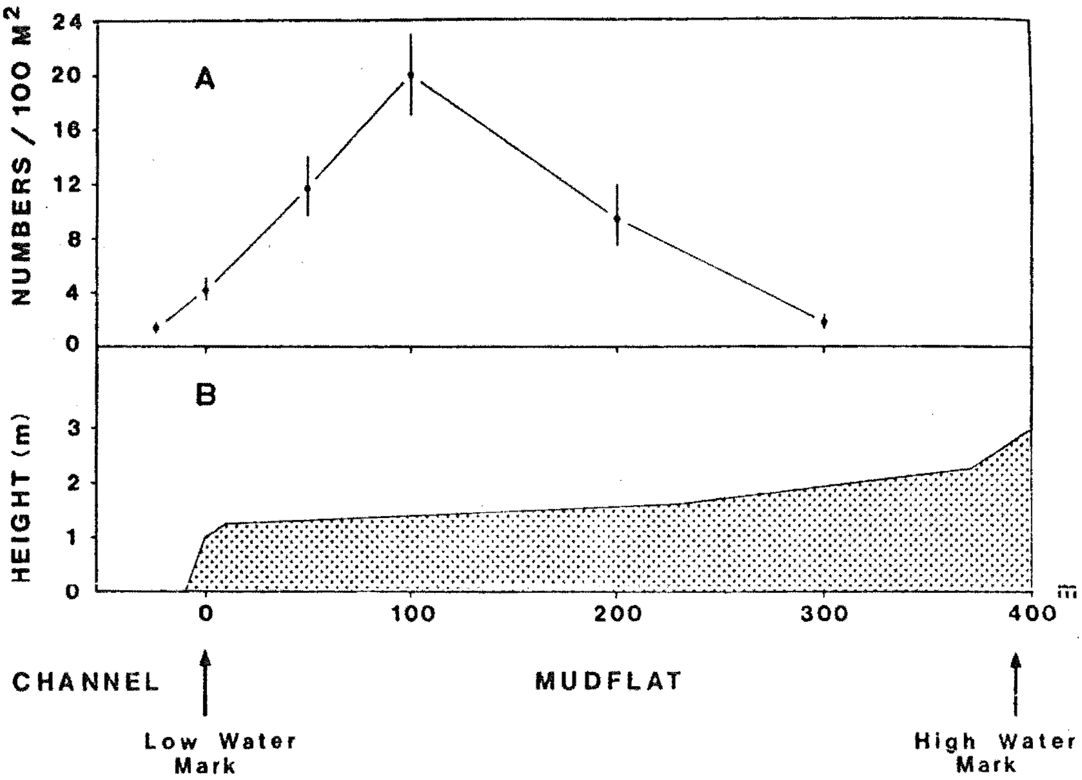


Fig. 19A: Mean number of 0+ sand flounder captured in trawls parallel to the shore at Station 3 in November 1970 (vertical bars show one standard deviation either side of the mean).

Fig. 19B: Cross-section of the channel and mudflat at Station 3 showing the position of the parallel trawls.

flounder occupy the intertidal region for 6-8 hours. From intertidal trawling and personal observations sand flounder were seen to have a similar surge into the intertidal region, although the period of time over which this extends is not known. Gibson (1973) studied intertidal movements in 0+ plaice Pleuronectes platessa which were observed to move up and down the shore with the tide during day and night. They tended to maintain their position at 1-2 m depth, and there was a significant relationship between size of fish and depth which was maintained as the tide ebbed and flowed. He discussed some factors which may control the maintenance of a particular depth distribution emphasizing sensing of pressure changes with depth. He also showed that 0+ plaice fed predominantly during the day, although some feeding occurred at night, the tide having no obvious effect on feeding.

(2) Dispersion - The results of the fish marking programme are presented in Table 15. No marked 0+ fish were recaptured amongst 1082 fish captured outside the locality of Station 3. However since it proved extremely difficult to systematically sample all regions of the Estuary because of an algal bloom, migration to other places cannot be excluded especially as only 31 out of a total of 1174 marked fish were recaptured. The low recapture rate could also have been due to mortality of marked fish that was not apparent in the laboratory marking experiments. The furtherest recapture was about 400 m from the release point at Station 3.

The percentage of fish recaptured was similar on different sampling days. Pearcy (1962) has suggested that percent recaptures of the same order over a short period indicate stability

Table 15: Number of 0+ sand flounder marked and recaptured at Station 3 (m = total no. marked, n = no. marked fish at large, c = total no. of fish examined, and r = no. of marked fish recaptured)

Date	m	n	c	r	% Recaptured
27/11/70	103	-	115	-	-
29/11/70	46	103	50	-	-
30/11/70	120	149	131	1	0.67
2/12/70	62	269	69	2	0.74
3/12/70	213	331	222	4	1.21
10/12/70	228	544	241	7	1.29
11/12/70	402	772	426	7	0.91
15/12/70	-	1174	337	10	0.85

of fish distribution during the study period. Macer (1967) recorded little movement between release points for 0+ plaice Pleuronectes platessa, and therefore the recaptures of 0+ sand flounder within a relatively confined area may indicate that they only migrate short distances.

Migration of 0+ sand flounder for only short distances may also correlate with the distribution of the different age classes in the Estuary. Few 0+ fish were captured near the mouth or head of the Estuary, the majority were in the middle reaches. Age 1+ fish are found near the mouth (Webb, 1966) and 2+ and 3+ migrate from the Estuary into the offshore waters (Mundy, 1968). These data indicate a discontinuous distribution between 0+ fish in the Estuary and those in offshore waters. Migration of 0+ fish within the Estuary, mainly from inferential data, suggests a population with a stable distribution, they appear to remain at the locality where they settled as metamorphosing larvae, most movements are intertidal onto the mudflats with the rising tide. In the long term there is a progressive movement towards the channels and mouth as they approach age 1+. This movement with age possibly correlates with maturation of gonads, change in susceptibility to low salinity and change in preferred depth of water.

7.6 General Discussion

Many studies of salinity tolerance and regulation of salt balance in fish have been carried out. Alderdice and Forrester (1968) have correlated experimental studies on salinity tolerance for English Sole *Parophrys vetulus* Girard with the distribution and survival of eggs and larvae in the field. Few studies have attempted these relationships for older fish and no material has been published on this subject for 0+ sand flounder.

Salinity is generally credited with setting the limit of distribution of a species into an estuary from the sea. Kinne (1964) has emphasized that there is a need to consider the combined ecological and physiological importance of temperature and salinity acting jointly. In the present investigation the effect of temperature has not been well covered and requires further attention; salinity has been emphasized, with temperature, currents and food availability being considered in more general terms.

The effect of the salinity regime of the Estuary on distribution of 0+ sand flounder could not be correlated with low salinities alone, nor to the rate of change of salinity (Alexander *et al.*, 1935) since the change in rates did not vary appreciably between Stations 3 and 6. Distribution of 0+ fish is determined by preference for only short periods of exposure to low salinities. This preference cannot simply be for higher salinities alone otherwise 0+ fish would not be found in these low salinities at all (ie. at Stations 4 and 5). As very young 0+ fish are more susceptible to low salinities they live in the middle reaches of the Estuary, where high salinities are experienced in the mudflat pools and streams throughout the tidal cycle even though the adjacent channels have freshwater flowing in them. The observed differences in distribution of different age groups of 0+ sand flounder will further reduce the competition between them for such things as food, and could have important effects on the production of the species.

Other factors modify the distribution of 0+ fish in relation to salinity, for instance, young individuals avoid high current velocities and they are not found at the mouth of the Estuary but in areas of more sluggish currents such as the middle reaches. Evidence was also provided that 0+ fish are more resistant to high temperatures at higher salinities, and are more abundant in areas of the Estuary where the mudflat pools are covered by highly saline water on the rising tide.

Sand flounder are benthic fish and they live in the bottom wedge of water of greater salinity than that found at the surface. Sand flounder were also observed to surge into the intertidal regions on the rising tide of highly saline water. From both of these behavioural adaptations and the partial euryhalinity it appears that sand flounder have extended their range into estuarine waters from offshore regions.

Distribution of sand flounder has been modified in other ways. Estcourt (1962) records young flounder being abundant in low tidal pools on the mudflat 800 m upstream of the Ferrymead Bridge. Webb (1966) records no flounders past the Ferrymead Bridge. During the present investigation few flounder were captured in the region 800 m downstream of the Ferrymead Bridge. Over recent years an increased pollution load has been carried by the Heathcote River and this could account for the withdrawal of sand flounder. Oxygen levels have been recorded that would be too low for the survival of most species of fish but with the recent removal of industrial wastes from the Heathcote River the water quality has improved and fish can be expected to enter the lower reaches of the river again (Knox and Kilner, 1973).

Sand flounder distribution has undoubtedly been modified by predation pressure. Sand flounder are eaten by the main predatory fish of the Estuary, red cod Physiculus bachus (Bloch and Schneider) and kahawai Arripis trutta (Bloch and Schneider). However, the distribution of 0+ sand flounder does not overlap with that of these two predatory fish which do not penetrate into the middle reaches of the Estuary (Webb, 1966). The eels Anguilla australis schmidtii (Richardson) and Anguilla dieffenbachi Gray may account for some of the 0+ sand flounder mortality. Predation pressure of wading birds such as South Island pied oystercatcher Haematopus ostralegus finschi Martens and Eastern bar-tailed godwit Limosa lapponica L. is not known, however, they have been observed to capture 0+ fish from mudflat pools during the course of the present study.

Distribution of 0+ sand flounder and especially the effect of salinity on their distribution will be used in Chapter 8 to assess the effect of the proposed barrier and channel dredging on their survival, as these proposals would cause marked changes to the salinity regime of the Estuary.

8. IMPLICATIONS OF PROPOSED ENGINEERING DEVELOPMENTS FOR FLOOD CONTROL ON THE BIOLOGY OF 0+ SAND FLOUNDER

8.1 Introduction

Christchurch is situated on low-lying land between the hills of Banks Peninsula, the Canterbury Plains, and the sea. The surrounding area is drained by the Avon and Heathcote Rivers which flow through the city to the Estuary. In times of prolonged, heavy rainfall or high spring tides parts of Christchurch are subjected to heavy flooding (Fig. 20).

In December 1959, following field and desk studies, Sogreah (civil engineers) of Grenoble, France reported that drainage of the land along the lower reaches of the Avon River could be improved by dredging the low water channel of the Avon and that tidal flooding could be reduced by building a barrier at the mouth of the Estuary. Sogreah recommended that hydraulic model studies should be carried out to explore the effects of such civil engineering works. In 1963 the Christchurch Drainage Board through its Consultants (Messrs Royds and Sutherland) requested the Hydraulics Research Station (HRS), Wallingford, England to investigate these and other means of preventing flooding in the city.

The report of HRS's research was published in July and August, Report No. EX509, 1970, entitled "Christchurch, New Zealand. Model Studies of Flood Alleviation". Following inquiries arising from some aspects of this first report, further tests were carried out and reported on in April, 1972. These reports are all referred to collectively as the 'Wallingford Report'.

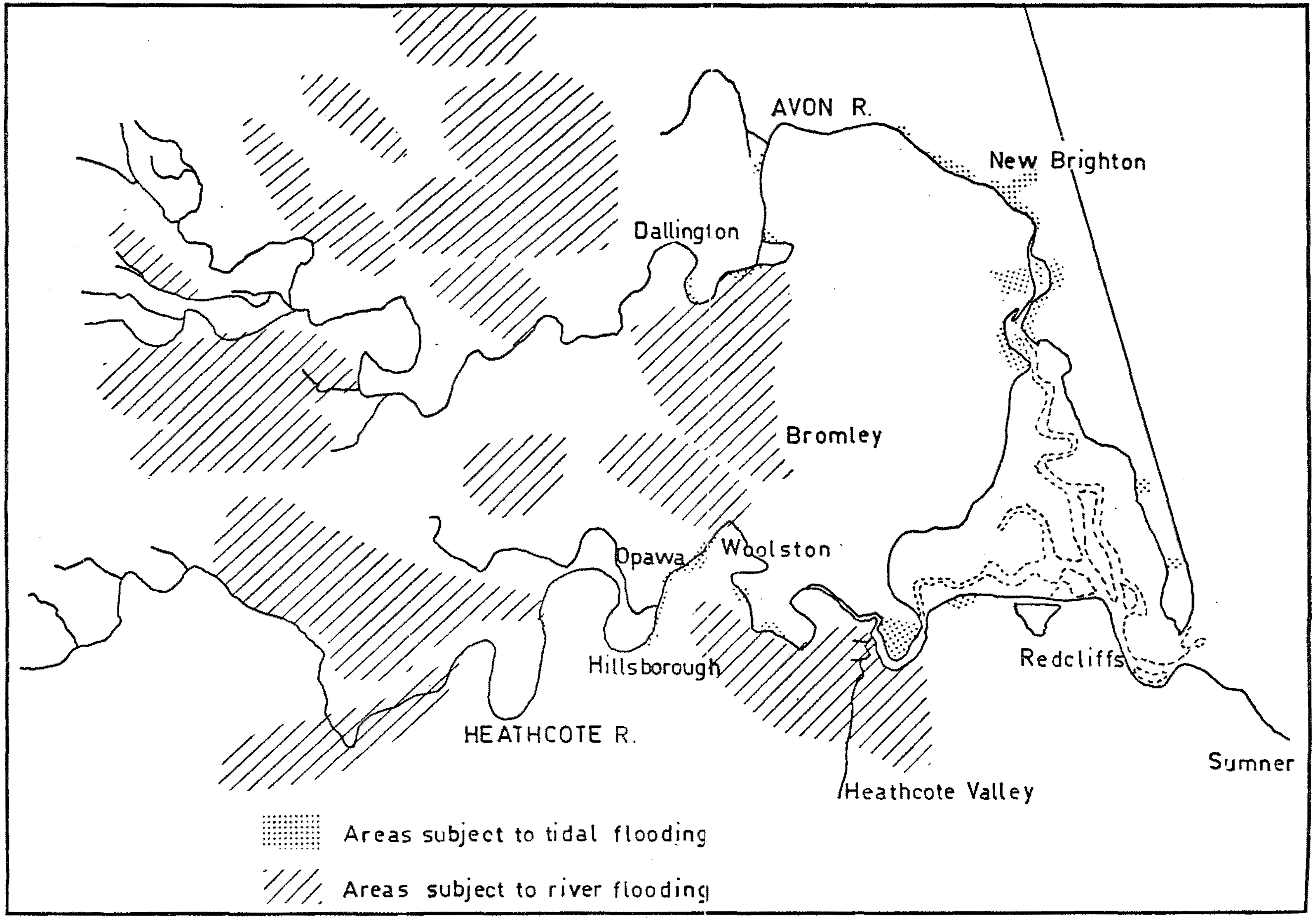


Fig. 20: The areas of Christchurch subject to flooding (after Wallingford Report).

The present study investigated the effects of these proposed schemes on the biology of 0+ sand flounder *Rhombosolea plebeia* (Richardson).

8.2 An Outline of Proposed Developments

HRS from their hydraulic model tests state that "flooding could be greatly alleviated by combining the operation of a movable barrier at the entrance to the Estuary with the implementation of specified schemes to deepen and straighten the rivers and low water channels. A barrier alone would merely provide protection against tidal flooding, leaving the problem of freshwater flooding largely unsolved. Straightening and deepening the rivers and low water channels, if unaccompanied by the operation of a barrier, would still leave Christchurch vulnerable to tidal flooding".

The drainage improvement schemes recommended for the Estuary are shown in Fig. 21. Several barrier positions were tested and sites at Redcliffs were preferred to Shag Rock because of the more sheltered position of the former from wave action. Different barrier designs were also tested, with gate numbers ranging from three to seven. Three 19.81 m wide gates were finally recommended.

The recommended low water channel dredging consists of straight channels with a bed width of 97.54 m, set at a level of 6.706 m (22 ft) Christchurch Drainage Board Datum (C.D.B.D.), with side slopes of 1/20, the dredged volume amounting to 675,000 and 375,000 cubic metres for the Avon and Heathcote Channels respectively. The level of 6.706 m C.D.B.D. gives a minimum depth of 1.524 m below low water. This dredging lowered the

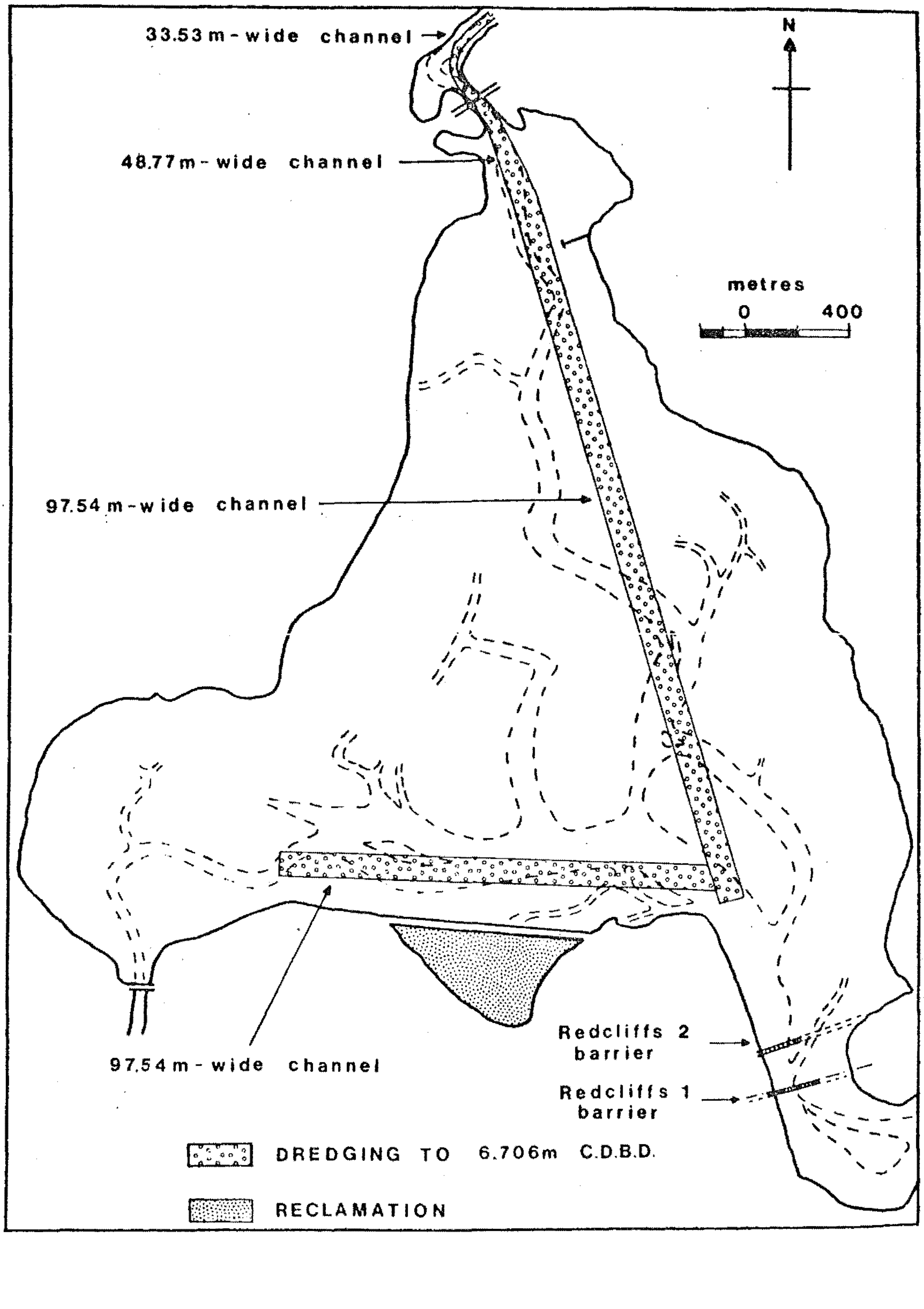


Fig. 21: Location of possible barrier sites and dredged channels for the Estuary (after Wallingford Report).

low tide water level at Bridge Street Bridge by 35.6 cm, and with a continuous channel dredged up the Avon Channel for 2.82 km to Baker Street the level was lowered to 68.6 cm. At Ferrymead Bridge the low tide level was 12.70 cm lower than before dredging. The 97.54 m wide channels were adopted from Sogreah's Report and the width was probably for it to be suitable as a rowing course. It does not appear to be known if narrower channels are as suitable for flood relief.

The Wallingford Report shows that minimum water levels are achieved in the Estuary by closing the barrier gates 1-1.5 hours after low water at Scarborough Lifeboat Station.

From the above it can be seen that there are two flood relief schemes, namely the barrier and the channel dredging, which for engineering purposes must operate in conjunction with each other. However for the analysis of the impact of these schemes on the ecology of the Estuary it is more convenient to discuss the barrier and channel dredging separately.

8.3 Possible Effects of the Barrier

The effect of the barrier on the following parameters has been studied because of their relevance to the biology of 0+ sand flounder.

Salinity

The barrier as described in the Wallingford Report would be closed 1-1.5 hours after low water at Scarborough when flooding was imminent. Closure is thus effectively very close to low water level in the Estuary.

Closure of the barrier would have a number of effects on the hydrodynamics of the Estuary. Closure at low water means that there will be the least possible amount of sea water present. In the subsequent days while the barrier remains closed the low saline water retained behind the barrier will become more and more dilute as the river water slowly fills up the Estuary. The mudflats will be exposed for a longer period of time than normal. They will be directly exposed to the rain that will probably be falling at this time. The pools on the mudflats which normally are quite saline will become diluted and eventually become fresh.

Salinities found in the Estuary under normal low river flows are shown in Fig. 4. Salinity data was also collected for the Wallingford Report (Fig. 10; HRS, 1970). The data of both studies are similar. The salinities at low water are of the most interest since they will be the conditions existing at the time when the barrier is closed. The low water salinities at Shag Rock were not less than $24^{o}/oo$. At Bridge Street Bridge and Ferrymead Bridge the salinities fell below $2.0^{o}/oo$ at low water. Linzey (1944) and Bruce (1953) obtained similar results for Bridge Street.

To obtain additional information on low water salinities, samples were collected on two occasions, once each at a spring- and neap-tide at a large number of sample stations (Fig. 22). Surface-, mid-, and bottom-water samples were obtained by boat, starting at the Redcliffs barrier site and then moving up the Estuary in front of the incoming tide so that all samples were obtained as near as possible to low water. The salinities in the upper (0.2-$7.0^{o}/oo$) and the middle reaches (7.0-$12.0^{o}/oo$) tend to be low (Table 16). The volume of water in these areas at low water is small, the volume of freshwater coming down the

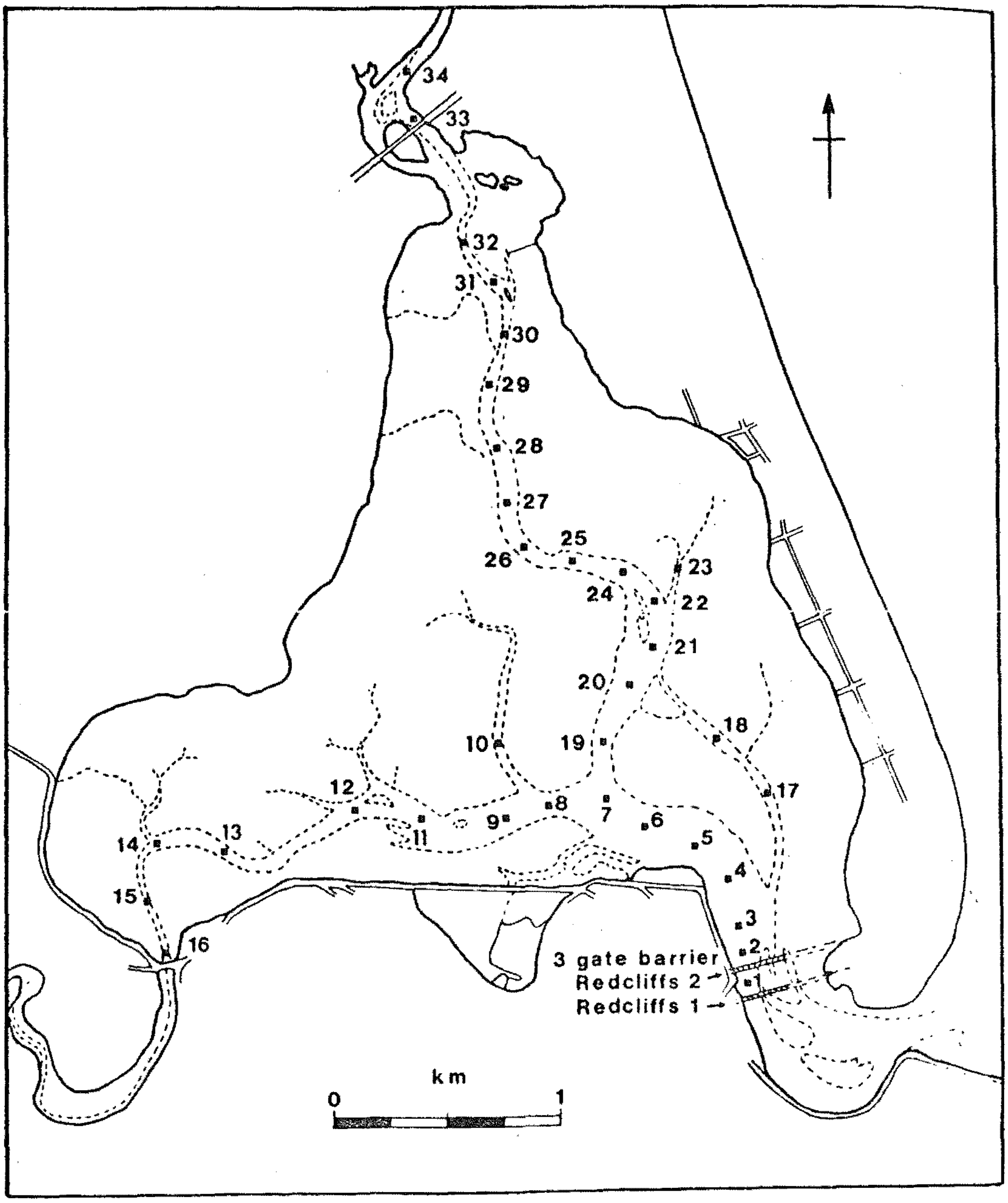


Fig. 22: Location of low water salinity stations.

Table 16: Salinities measured at the stations shown on Fig.22.

	Surface		Mid		Bottom	
	Range	$\bar{x}$ *	Range	$\bar{x}$ *	Range	$\bar{x}$ *
1	20.2-22.4		21.0-23.2		21.1-23.9	
2	21.6		21.5		22.1	
3	19.5		21.0		21.4	
4	18.1-32.0	25.4	18.9		17.4-30.0	22.1
5	19.4		21.4		21.7	
6	12.0					
7	18.0-20.1		18.6-18.9		19.6-19.9	
8	17.0					
9	15.8-15.9		16.9-17.7		18.0-19.1	
10	17.0					
11	13.4-25.3	18.1	14.1-15.8		13.6-25.2	20.7
12	11.3-14.0		11.3-14.3		11.6-14.6	
13	6.8-10.2		6.6-10.4		7.1-11.1	
14	3.5- 5.2		5.3- 6.3		6.8- 8.1	
15	3.3- 3.6		3.0- 3.8		3.0- 4.3	
16	2.3-19.5	8.3			1.8-19.5	9.3
17	18.7-20.4					
18	18.6-19.5					
19	6.9- 8.5					
20	5.5- 8.6		5.9- 8.3		6.9- 8.1	
21	4.0					
22	3.0- 7.2	5.2	3.6- 7.4	6.4	6.3- 8.5	7.3
23	3.8					
24	1.7					
25	1.3-14.8	6.4	1.8- 4.0		1.9-16.3	7.4
26	1.0					
27	0.6- 1.0	0.8	1.4- 1.9	1.6	2.1- 3.2	2.6
28	0.5					
29	0.4					
30	0.3					
31	0.4- 0.6	0.71	0.4- 0.8	0.73	0.4- 0.8	0.74
32	0.8					
33	0.2- 0.7	0.29	0.2- 0.8	0.3	0.2- 0.8	0.3
34	0.2		0.2		0.3	

* The mean of at least five measurements.

rivers under flood conditions would soon be greater. Even assuming complete mixing the salinities in these regions would be extremely low.

Salinity measurements were made for the Wallingford Report during floods in April 1965 (Fig. 11; HRS, 1970). Surface values only were taken, which could be expected to be the most sensitive to changes in river flow, but the high water value of 5.5^{o}/oo at Bridge Street Bridge was at least 20^{o}/oo lower than the normal river flows. The effect was more marked at Ferrymead Bridge, the maximum salinity under flood conditions was 2.0^{o}/oo compared with the usual 30^{o}/oo.

The data demonstrates that a large volume of flood water coming down the rivers can have considerable effect on the salinity of the upper parts of the Estuary at high water. The effect will be even more marked at low water (ie. the time of barrier closure) because there will be less sea water in the Estuary and no tidal pressure for the flooding river water to overcome. On the basis of the above information it is probable that the upper and middle reaches of the Estuary will have salinities less than 1.0^{o}/oo when the barrier is closed.

The interstitial salinities are similar to the mean salinity of the overlying water and tend to remain relatively constant, not being altered by the overlying water to a marked extent (Voller, 1973). These interstitial salinities possibly could have some effect in raising the salinity of freshwater held for extended periods of time by barrier closure. However, the large volume of freshwater from floods probably means that interstitial salinities would have a slight effect only for several millimetres depth above the sediment surface.

It was originally intended to determine the salinities of the low tide water, the respective volumes of water of these salinities and obtain an average salinity for low tide water. Using this information flood conditions could be simulated by progressively adding freshwater, using the projected 2, 5, 10, 20 and 50 year flood flows (Mawson, 1972), to measure the decrease in salinity of the Estuary water. However, it is now considered that equal mixing of the low tide Estuary water and the flooding river water would not occur. The bulk of the saline Estuary water would be confined to the deep channels immediately upstream of the barrier. The flooding freshwater would tend to bank up behind this saline water and spread out over the mudflats. Mixing would not be aided by tidal currents as usual, the principal mixing agency in this case would be reduced to the action of the wind. Therefore such an experimental exercise would serve no practical function.

Since the freshwater will tend to remain as a compact mass, and as there will be only a small volume of saline water in the channels at low tide, the salinities in the middle and upper reaches of the Estuary will remain extremely low. These low salinities, probably less than $1^{o}/oo$, will be directly affecting the intertidal animals and fish of the main mudflat areas.

Exposure Times

Exposure time is the number of hours per tidal cycle that a particular level in the intertidal zone is exposed to the air and uncovered by water. Closure of the barrage would radically change the exposure times at different points in the Estuary.

If the barrier were to be closed about 1.5 hours after low water at Scarborough, at this time it is estimated that approximately 980,000 cu. m of water would be present in the Estuary basin. Given the flood conditions of 1968, 1360 cu. m /min from the Heathcote and 680 from the Avon, the inflow per tidal cycle would be:

Avon River	483,840	cu. m
Heathcote River	967,680	" "
Other inflows	65,318	" "
Total	1,516,838	" "

Since the mean volume of water entering per tidal cycle has been estimated by Mawson as 8,237,824 cu.m per tidal cycle it would take nearly 5.5 tidal cycles to fill the Estuary to its mean level, ie. under three days. The time taken for the Estuary to fill will, of course, be dependent upon the intensity of the flood. In the 50 year river discharge Mawson has estimated that the total freshwater inflow during a tidal cycle would be of the order of 5,600,000 cu. m. Thus the Estuary would fill to two-thirds of its mean capacity in one tidal cycle.

Thus depending on the time of closure and the volume of river discharge some of the mudflats would be exposed to the air for continuous periods of up to three days under moderate flood conditions (Knox and Kilner, 1973).

Nutrient Distribution and Coliform Bacteria

Under the present discharge conditions there is no doubt that barrier closure would accentuate the current eutrophication problem. Nutrient rich water from the Bromley Sewage Works and the rivers would be trapped within the Estuary. While some dilution of the Oxidation Pond effluent would occur within the Estuary by mixing with the incoming river water, nevertheless the dilution would be small compared with the dilution that occurs with the incoming tide.

Mudflats which are only covered by water for part of a tidal cycle would become covered by water continuously for several tidal cycles. Coverage by water with high reactive phosphorus and inorganic nitrogen levels for extended periods would mean that increased amounts of these nutrients would pass into the sediments (Knox and Kilner, 1973).

The operation of the barrier will increase the coliform bacterial levels within the Estuary. Firstly, the Bromley Sewage Works effluent will be retained for a much longer period within the estuarine basin and, secondly, as the water within the Estuary will be of low salinity the dieoff that occurs when the coliforms come into contact with seawater will not occur (Knox and Kilner, 1973).

Sediment Biota

The invertebrate animals forming the estuarine benthic community have specific ranges of salinity, sediment particle size distribution and intertidal exposure within which they occur (Voller, 1973). Since the operation of the barrier would alter both the salinity regime and the intertidal exposure times on the mudflats the effect on the benthic invertebrates would be severe, especially if the barrier were closed for any extended period. Those animals most likely to be severely affected would be those with the lowest salinity tolerances such as the pipi *Amphidesma australe australe* (Gmelin) and the polychaetes *Aonides trifidus* Estcourt and *Haploscoloplos cylindrifer* (Ehlers).

Barrier operation for more than a limited period would be likely to result in the death of such species (Knox and Kilner, 1973).

The cockle Chione stutchburyi Gray, is the dominant species of the estuarine community. It is found below mid-tidal levels and has a salinity tolerance range from sea water to $18^{o}/oo$. Voller found it would not feed below $18^{o}/oo$ and that it could live four days under these experimental conditions. Since the salinities on the Estuary with the barrier closed would be well below $18^{o}/oo$ any prolonged closure could have a catastrophic effect on the cockle populations resulting in massive mortalities. Large scale cockle deaths would lead to the loss of a major food source for 1+ and 2+ flounder.

Sand Flounder

(a) Migration - Larval sand flounder migrate into the Estuary from July to November inclusive (see Chapter 3.4). Peak numbers enter during August to October. Barrier closure during these months may affect the larval sand flounder.

Death naturally occurs of very large numbers of larvae not entering favourable estuaries or bays. Most of those that do enter these places die because they do not settle in favourable conditions of salinity, food, current velocity, temperature and pollution for survival.

The barrier will cause the death of those larvae swept into the Estuary during a closure period, however, once the barrier is reopened succeeding flood tides will bring other larvae into favourable areas. The survivors develop to provide the population ranging from 11,000 to 53,000 fish aged one to three years (Mundy, 1968). Therefore if the barrier is closed for short periods of only 2-3 days at a time, there will be little or no disruption of the life history of the sand flounder because large numbers (probably millions) will be able to enter the Estuary when the barrier is open.

Mundy showed by analysis of returns from tagged fish that there was extensive movement of sub-adult and adult sand flounder from the Estuary to the offshore grounds annually. The greater part of this movement took place from July to November. He calculated that the number leaving the Estuary was likely to be in excess of 20,000 fish. Again it would appear unlikely that barrier closure for 2-3 days will have a serious effect on the migration of these fish.

(b) Salinity - The young sand flounder's relationship to salinity under normal field conditions is a valuable guide to the effects that will be produced by the non-normal conditions of the barrier. The agreement of the field distribution of sand flounder in relation to salinity and the salinity experiments (see Chapter 7) indicates that the use of the experimental results for assessing the effects of the barrier has some validity.

The experimental design was arranged so that fish were exposed to severe conditions in order that a baseline could be established where they would be expected to survive better in the field than in the experiments for predictions of the effect of the barrier. The experimental temperatures of about 15^{o}C were higher than most of the monthly mean water temperatures of the Estuary, and it is unlikely that these temperatures assisted their survival. It is commonly found that flounders survive low salinities better at colder temperatures (von Westerhagen, 1970). However, it is known that organisms can commonly tolerate a lower salinity in laboratory experiments than in their normal environment (Riley, 1967).

The results of the salinity experiments (see Chapter 7) show that for salinities less than $4.0^{o}/oo$ there is reduced survival with increasingly lower salinities. The median survival time in freshwater was 43 hours, in $0.5^{o}/oo$ was 64 hours, and in $1.0^{o}/oo$ was 90 hours.

Estuary salinities in the middle regions, the preferred habitat of young sand flounder, could be $1.0^{o}/oo$ or less (see earlier). It is probable that they will experience salinities of 0.5-$1.0^{o}/oo$ rather than freshwater. They are bottom living creatures and will benefit from the greater density of sea water (causing it to lie under freshwater) and also from the effect that interstitial salinities may have on the thin layer over the sediment surface. Therefore the length of exposure between 64 and 90 hours is the critical period for the survival of fish before sea water flushing must be resumed by opening the barrier. The nature of the experimental design was arranged so that in the field fish could be expected to survive even better than in the experiments. Even so to provide for a safety factor a time less than 64 hours must be adopted to protect sand flounder survival. A maximum of 2-2.5 days for the Estuary to have no tidal flushing is strongly recommended. Even with this time some of the more sensitive young flounder will perish, however the majority will survive and grow into adults to replenish the offshore stocks. Raj (1973) found that adult sand flounder were susceptible to salinities below 12.6-$13.6^{o}/oo$ after 20-60 hours exposure, therefore a shorter time of barrier closure may be desirable to protect these older fish, though they may gain protection by tending to be only found in the deeper channels near the mouth where the salinities are high.

(c) Nutrient Distribution and Coliform Bacteria - The enrichment of the sediments may alter the types of sediment and the distribution of food species. An increase in area covered with fine sediments and the protozoan Euglena would reduce the available food supply. Fine sediments and high organic matter also could lead to predominance of detritus feeders, species like Amphibola crenata (Martyn) are not commonly eaten by 0+ sand flounder.

Accumulation of effluent and coliform bacteria may have an adverse effect on flounder. The organic load could lead to oxygen depletion. Webb (1966 and pers. comm.) noted that flounder caught near the Oxidation Pond effluent had a mucous coated surface that was not present on those near the sea. He thought that the production of mucous was a response to irritation of the skin.

(d) Exposure Times and Sediment Biota - Mortality of those food species with low salinity tolerances and low tolerance for exposure would have a long term effect on the flounder. Loss of the cockles would not be serious for 0+ fish but would restrict the production of older age classes.

Restriction to the channels while the barrier is closed may lead to increased predation on the 0+ flounder. Restriction in a confined space for a long period will increase the chance of contact between the predator and the prey.

(e) Feeding - When the barrier is closed under flood conditions similar to those occurring following the 1968 'Wahine Storm', the Estuary would take 5.5 tidal cycles (ie. less than 3 days) to fill to mean water level (see earlier). For at least the first day of closure and perhaps longer the mudflats would be exposed and only gradually be covered. At such times 0+ sand flounder would be confined to the low tide channels and could not move out onto the mudflats to feed.

It is not known what food can be obtained in the channels, but observations made by Dr A.R. Mundy (pers. comm.) and the author indicate that sand flounder captured in the channels at low tide have emptier stomachs than those caught over the mudflats. The inference drawn from these observations is that feeding occurs on the intertidal regions of the mudflats. Whether feeding in the channels could make up for not being able to feed on the mudflats, or even whether 0+ fish can survive three days on a reduced diet is unknown. The food supply in the channels is limited as the area of the channels is small compared with the mudflats, and low densities of food are probable in the channels compared with the intertidal regions because of continuous predation by fish in the channels. Smidt (1951) noted such differences in food densities between channels and intertidal areas where plaice Pleuronectes platena L. fed in the Danish Waddensea. Feeding may also be limited in the channels by the salinity decreasing to low levels as fresh water accumulates behind the barrier, as it was observed during salinity tolerance experiments that the amount eaten was less in low salinities and very little was eaten by fish living in freshwater.

In the present investigation fewer 0+ fish had empty stomach compared with the older age classes studied by Webb (1966). Ricker (1946) noted as a general rule "that larger fish more often have empty stomachs than do smaller ones of the same species". This has been attributed to larger fish being able to live longer without feeding than the smaller, more active and faster growing individuals. If smaller sand flounder have to feed more frequently, then curtailment of their movements onto the mudflats would have a deliterious effect on their survival, the extent of which is not known.

The lack of a tidal rhythm may also affect the rate of feeding or whether diurnal feeding occurs. Gibson (1973) found for 0+ plaice that the tide had no obvious effect on their feeding except that the fish maintained their position in 1-2 m depth of water. A similar pattern of behaviour in sand flounder with the barrier closed would restrict them to a narrow range up the shore. Graham (1956) considered that sand flounder feed by night but personal observation in the laboratory and field indicate that feeding during daylight predominates. Under conditions of barrier closure the length of the period spent feeding could possibly increase to cope with the limited food available.

Circumstantial evidence indicates that the survival of 0+ sand flounder may be adversely affected by the barrier altering the natural feeding patterns and affecting the survival of the food species, but the extent of this cannot be accurately determined.

8.4 Possible Effects of Dredging

Exposure Times

The channel dredging and straightening is necessarily associated with the barrier (Wallingford Report). The dredging will reduce the low tide levels by 35.6 cm at Bridge Street Bridge and 12.70 cm at Ferrymead Bridge. This reduction indicates a decrease in area of mudflat covered by water at low tides, ie. an increase in exposure time for the mudflats.

The large scale of the dredging operation means that on the flood tide the dredged channels will be able to contain more water than at their present natural state, and a delay will occur before the water fills the channel to the top and starts to spill over the mudflats. The exposure times will be lengthened because of this delay.

The exposure times also could be altered by the straightening of the channels. The present meandering channels provide a dampening effect so that there is a delay between the tide turning and the water flowing off the mudflats. With straight channels the water will flow off the mudflats much sooner after the turn of the tide. However the reverse is also true that water will flow more quickly onto the mudflats with the flood tide. What difference in exposure times would result could not be calculated.

The change in exposure times will affect the sedimentation patterns over the Estuary. The less time water covers the mudflats the less chance for fine sediments to settle (Voller, 1973). This feature will alter the distribution of the intertidal animals.

Current Velocities

During the hydraulic model tests the Estuary channel velocities after dredging were not directly measured by HRS. However, it can be inferred from the tidal curves of Fig. 25 from HRS (1970) that dredging increased the tidal discharge and that since the ebb tide was reduced by one hour, ebb current velocities would be higher and flood velocities lower than before dredging (Christchurch Drainage Board Report, June, 1972). The reduction in the low tide water levels and the removal of the meandering channels allows this faster ebb current flow.

With the change in current velocities the sedimentation pattern of the Estuary will alter as current velocity is the principal agent in determining these patterns for the Estuary (Voller, 1973). Changes in sedimentation will alter the distribution of intertidal animals.

Salinity

The Wallingford Report states that with dredging "high water level was raised by about 5.08 cm at Bridge Street Bridge, due to the increased tidal penetration.........At Ferrymead Bridge high water level was virtually unchanged". With increased tidal penetration the saline water can be expected to penetrate further up the Estuary, the distribution of some species may be extended. Overall the increased tidal penetration is unlikely to have a marked effect on the general salinity regime of the Estuary. The saline water will flow out of the Estuary more quickly due to higher ebb current velocities. The main effect will be that the rates of salinity change will increase in the immediate vicinity of the dredged channels. The change is unlikely to be great enough to be deleterious to animal life.

Sediment Biota

As far as the animals living on and in the sand and mudflats are concerned, dredging would bring the greatest changes in numbers and distribution. This would be due to a combination of resulting changes in salinity distributions, current patterns, exposure times and sediment particle size, as well as the physical changes due to the dredging process itself.

Dredging would involve the physical removal of the animals and the deposition of sediment, especially the fine black anaerobic muds, on others. Whenever dredging took place the character of the sediments would be changed and although a new fauna would establish itself on the newly created bottom it would differ in character to that which previously occupied the same sites.

The proposed dredged channels would result in the loss of many of the low tidal side streams. At low water the volume of water in the Estuary would be concentrated in the dredged channels and would not be spread over as great an area of the intertidal flats. The consequent changes in exposure times in the intertidal region would result in changes in distribution patterns and the disappearance of some species from shore levels where they are found at present. Competition for space is likely to increase.

It is difficult to assess the precise changes that would occur in sediment particle size distribution. However, the changed current patterns and velocities would lead to some areas becoming muddier and some sandier. The probable overall effect of the dredging would be to decrease the diversity and numbers of the estuarine benthic animals with consequent effects on those species that depend upon them for food (Voller, 1973; Knox and Kilner, 1973).

Sand Flounder

(a) Exposure Times - The natural meandering form of the low water channels allows for many mudflat streams to form over the mudflats. These streams contain saline water at low tide (see Chapter 7.4) and are the principal habitat of the young developing sand flounder.

With the increased exposure time of the mudflats and the reduction in the water level at low tide the mudflat streams will completely drain. This will force the young fish into the main channel at low tide where their chance of survival will be much lower. In the main channels they will encounter a number of hazards normally avoided in the mudflat streams; increased water velocities, low salinities from the river water replacing the saline water towards low tide and probably increased predation from other fish.

The increased exposure times will probably affect sedimentation patterns, current velocities and thus distributions of intertidal animals. The change in distribution of intertidal animals, especially any reduction in numbers will result in less food for sand flounder feeding, leading to fewer fish being supported by the Estuary.

(b) Current Velocities - Current velocities were measured in the main distribution area of young sand flounder. The maximum bottom velocities recorded in the channel reached 1.2 m/sec. The very small sand flounder are rarely found in the channels yet within a few metres in mudflat pools and streams they may be found. One of the factors responsible for this difference is swift currents in the channels; larvae and very small fish are swept away, and small fish avoid these currents because extra energy is required to maintain their position.

The reduction in water levels at low tide will empty mudflat streams, forcing young fish into the channels, where the ebb current velocities will be even higher than at present, and adversely affecting their survival.

(c) Salinity - Again young sand flounder will be affected by the dredging emptying the mudflat streams, forcing the fish into the channels where lower salinities will be encountered.

(d) Direct Mortality from Dredging Operations - It is considered that the dredging operation will directly cause large scale mortality of many species of fish in the Estuary including flounder. Webb (1966) reported that on October 14, 1965 paralysis and death occurred of large numbers of young mullet, flounder and whitebait. The water was chocolate coloured and emitting a strong smell of hydrogen sulphide originating from the operation of a dragline in the Estuary near Linwood Avenue Culvert. The mud, when disturbed, went into suspension allowing the poisonous gases of decay to dissolve into the water and incapacitating the large fish population.

The magnitude of dredging as described in the Wallingford Report, even if a pumping operation rather than dragline was used, would cause disturbance of the sediment with gas release and large scale fish deaths. For instance the dredging would cut through the main area of young sand flounder development and cause large scale mortality.

The effect on depletion of fish stocks is likely to be continuing if straight deep channels are to be maintained as dredging would then have to occur at regular intervals.

(e) Proposed Aquatic Playground Proposals - The proposals for dredging the estuarine basin for aquatic sports (Wallingford Report) have been opposed by HRS on civil engineering grounds. The dredging required to carry out these proposals would have deliterious effects as mentioned above leading to large scale mortality of the benthic invertebrates and fishes. The proposed maintenance of a permanent water level (Christchurch City Council, 1972) would result in the intertidal Estuary no longer existing. A large part of the present estuarine biota which depends on the alternate covering and uncovering of the mudflats would disappear (Knox and Kilner, 1973).

8.5 Conclusion

The two engineering schemes, the barrier and the channel dredging have different effects on the sand flounder biology. The barrier has little consequence if barrier closure is restricted to 2-2.5 days or less for flood control purposes only. Channel dredging has long lasting effects. The reduction of the low tide water levels forces young fish into conditions of high current velocities and low salinities, and probably affects their food supply. The maintenance of dredged channels will result in each year class of fish being depleted in the Estuary, so that the corresponding year class would be reduced in the following years of offshore commercial catches. The effect on the offshore catches would not be noticed for 3-5 years until the fish mature and migrate offshore. Therefore the dredged channels will have a persistent effect on the biology as long as they are maintained.

9. CONCLUDING STATEMENT

Aspects of the biology of 0+ sand flounder in the Avon-Heathcote Estuary have been studied to complement the studies of Webb (1966) and Mundy (1968). An understanding of their biology was essential for estimating the effect on them of the proposed barrier and channel dredging in the Estuary. Evaluation of the effect on the total fauna is also required as any decrease in food species must result in a decrease of sand flounder being recruited into the commercial fishing grounds.

The Estuary because of its proximity to a large population and being regarded by many as 'wasteland' is open to abuse, reclamation, pollution etc. All schemes involving alteration of the natural estuarine environment should be considered by a controlling body using conservation and management policies similar to that detailed in Knox and Kilner (1973). Such considerations should include an evaluation of the effect on sand flounder. The Estuary supports a large important population of predominantly undersized sand flounder. Destruction of the estuarine habitat will have an immediate and direct effect on the abundance of sand flounder and reversal of such effects will be slow. Fortunately for the future of sand flounder most of the bays and inlets of Banks Peninsula support a juvenile flounder population and the isolated nature of these areas should ensure their continuation as nurseries for many years to come, however the relative importance of these areas as nurseries is not known. While only sand flounder from the Avon-Heathcote Estuary were studied in the present investigation, the information obtained

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should be applicable on a general basis to other nursery areas of this fish.

Lake Ellesmere is one area that requires further careful evaluation. The potential of this area as a nursery for sand flounder is high. Steps should be taken by the appropriate authorities to regulate the opening of the Lake to the sea at the correct time of the year for recruitment of eggs and larvae. If the Lake was opened to the sea each year during August, September or October, eggs and larvae would be expected to be carried into the Lake and allow stocks of fish to build up. The widely fluctuating annual catches of flounder in the Lake are mainly due to the irregular opening of the Lake to the sea.

It is hoped that this preliminary study of 0+ sand flounder promotes interest and further detailed research into their biology.

10. SUMMARY

1. This study is concerned with aspects of the biology of 0+ sand flounder Rhombosolea plebeia (Richardson) in the Avon-Heathcote Estuary, New Zealand.

2. The study area is located immediately north of the volcanic mass of Banks Peninsula (latitude $43^{o}32$'S., longitude $172^{o}43$'E.). The local climate is reasonably uniform and water temperatures ranged between 7 and 21^{o}C. The Estuary is moderately eutrophicated with high phosphorus and nitrogen levels resulting from pollution from the industrial area of the nearby city of Christchurch and the effluent of the Christchurch Drainage Board's Sewage Works.

3. A qualitative study of larval sand flounder using a plankton net indicated that they enter the Estuary for five months from July to November.

4. The 0+ sand flounder population was sampled with a beam trawl. Sampling efficiency of the trawl was not estimated because of marked seasonal changes in other sampling factors (eg. density of algal growth) but from overseas experience using beam trawls to capture juvenile flatfish the escapement is expected to be high.

5. Preliminary mesh size experiments indicated that 1.27 cm ($\frac{1}{2}$ in) stretch mesh caught the most representative sample of 0+ fish.

6. Catch per unit effort varied widely from month to month and could not be used to measure abundance, nevertheless

0+ fish were more abundant in October to December the period over which they were recruited into the population as newly settled fish.

7. Monthly length frequency analyses provided visual evidence of the growth of 0+ fish from month to month. For several months from August to November two modes were present resulting from the extended spawning season of this species. Length frequency analyses also provided evidence for the time of recruitment of newly settled fish into the population sampled, and the migration of 0+ fish into different habitats with growth.

8. Length : weight relationships were calculated and for most samples the b coefficient was not significantly different from 3.0 indicating that 0+ fish were growing isometrically. Deviations from 3.0 occurred in samples taken in the months when very young fish were being recruited into the population, probably showing that these fish do not have isometric growth.

9. From the length : weight relationships changes in condition were considered in terms of smoothed mean weights calculated from a pooled regression of all samples. Condition of 0+ fish showed a marked seasonal cycle with decreased condition in spring and early summer when young fish are being recruited into the population, followed by a rapid increase in condition by mid summer and a gradual reduction towards late winter.

10. Age 0+ sand flounder fed predominantly on benthic invertebrates; polychaetes, amphipods, decapods and siphons of bivalves were the most common animal groups. However, sand was the major constituent of the gut contents.

11. The diet shifted from smaller to larger food items with increasing age of fish, and also varied to a certain extent on a seasonal basis and between different regions in the Estuary.

12. A seasonal cycle in intensity of feeding appeared to be correlated with water temperature, however the potential gut volume was never fully utilized; the highest percent occurrence of food was 76.8% by volume (January) and the lowest was 39.4% (July).

13. Distribution of 0+ sand flounder in the Estuary was correlated mainly with salinity and current velocity.

14. Age 0+ fish were found to be increasingly susceptible to salinities of $4.0^{\circ}/oo$ and below, and very small fish were more susceptible than larger 0+ fish. The susceptibility with size was correlated with the field distribution; very small fish tend to be found in streams and pools where salinity remained high ($> 21^{\circ}/oo$) throughout the tidal cycle, and larger fish in the channel where the salinity dropped to low levels ($5^{\circ}/oo$) at low tide.

15. Surges of 0+ sand flounder into the intertidal region on the rising tide were observed.

16. It was suggested that the distribution of 0+ fish reduces predation upon them by other fish, and that differences in distribution of different sizes of fish and the surges of fish into intertidal regions reduce competition between them for food.

17. A preliminary mark and recapture experiment carried out over a short period indicated that 0+ fish may remain in a restricted area and not move freely about the Estuary.

18. Factors associated with the proposed barrier scheme for the Estuary which may affect survival of 0+ sand flounder were analysed. Providing the barrier was closed for short periods of only 2-3 days, there would be little effect on the recruitment of larval sand flounder to the Estuary. However, since salinities in the middle reaches of the Estuary, the preferred habitat of 0+ fish, would be well below the critical level of 4^{o}/oo below which there is reduced survival, many would die if they were subjected to such conditions for periods longer than 64 hours.

19. As the operation of the barrier would alter the salinity regime and intertidal exposure times of the Estuary, the effect on the benthic invertebrates would be severe if the barrier were closed for an extended period. Mortality of those species which are food for 0+ fish would have long term effects on the production of sand flounder.

20. Analysis of the proposed dredging schemes for the Estuary indicate that increased exposure times and drainage of the mudflat streams will reduce the available habitat for 0+ sand flounder. Changes in the distribution and abundance of their food organisms would also affect 0+ fish numbers and distribution. The dredging operations would lead to considerable mortality through release of poisonous gases from the sediments.

21. Proposals for use of the Estuary as an aquatic playground and for maintaining a permanent water level would cause large scale mortality of benthic invertebrates and 0+ sand flounder leading to depletion of the offshore commercial stocks of flounder.

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APPENDIX

Kolmogorov - Smirnov statistic, Dmax

Dmax is defined as the absolute value of the largest difference between two relative cumulative frequency distributions, one expected and the other observed (Sokal and Rohlf, 1969). It is of particular value when testing the output of computer programs that generate theoretical normal distributions with a mean and variance identical to the sample mean and variance, which are compared with the sample distribution.

Rohlf and Sokal (1969) present a table giving critical values for Dmax at a number of probability levels, for sample sizes between 1 and 100. Observed values of Dmax greater than critical values presented in the table are significant.

For sample sizes greater than 100 the two-tailed critical values are:

$$D_{0.05} = \frac{1.358}{\sqrt{N}}$$

$$D_{0.01} = \frac{1.628}{\sqrt{N}}$$

R x C contingency test, G statistic

Biological variables may be distributed into two or more classes, depending on some criterion such as arbitrary class limits in a continuous variable or a set of mutually exclusive attributes. An example of the latter would be a frequency distribution such as the frequency of individuals of different food species from gut samples of fish. For any such distribution the frequencies of the various classes represent certain parametric proportions of the total frequency. The R x C contingency test using the G statistics, tests for independence of classes in the frequency distribution (e.g. independence of major food categories between samples) and is a measure of the goodness of fit of the observed frequency distribution to the expected frequency distribution (Sokal and Rohlf, 1969).

In examination of gut samples (Chapter 6) the expected frequency was based on the hypothesis that the different food species could be expected in equal proportions.